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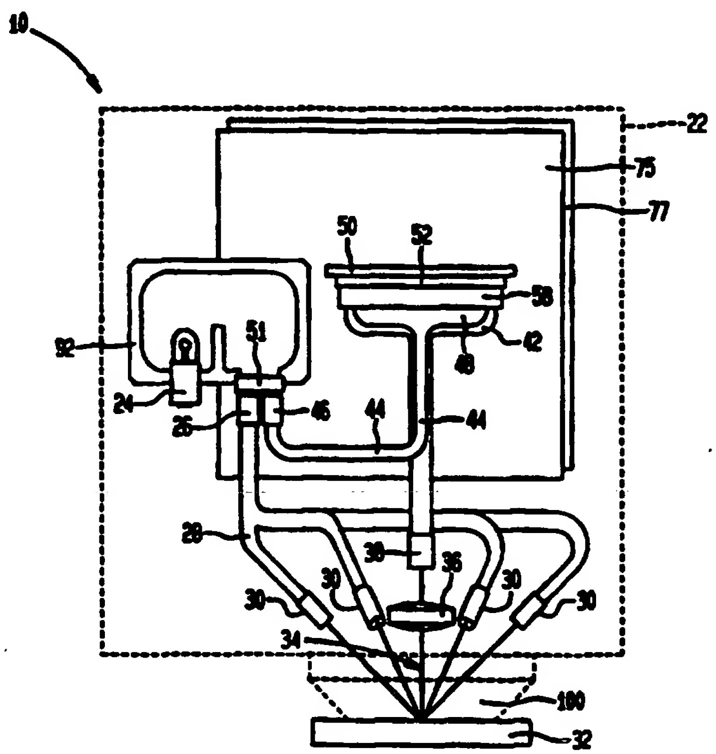
(57) Abstract

There is provided a portable, high precision color measuring device (22) for measurement of color of non-self-luminous objects. A spectral analyser (58) separates light reflected from an object (32) into spectral components and produces signals corresponding to the levels of spectral components of the reflected light. The device utilizes a dual beam (40, 44) reference system and an illumination homogenizing chamber (92) to negate the effect of instrument component variations and ensure high precision measurements at any instrument orientation. Also, the device optimizes its measurements by adjusting the gain level of each signal produced by the spectral analyzer with a programmable gain amplifier (84, 86). In addition, the device includes various features that compensate for variations in light source intensity and illumination, color temperature, displacement of the device during measurements, alteration of control button position, and adaptability to various optical geometries.



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PORTABLE COLOR MEASURING DEVICE

BACKGROUND OF THE INVENTION

I. Field of the Invention

The present invention relates generally to signal measuring devices or instruments for the measurement of the color of objects, such as spectrophotometers, colorimeters, spectrocolorimeters, radiometers and spectroradiometers. More particularly, the present invention relates to portable, hand-held color measuring devices that utilize a unique dual beam color measurement system.

II. Description of the Prior Art

Color measuring devices are generally used to measure the color of objects either directly using a broad band technique or on a wavelength basis, which data may be manipulated to yield colorimetric data. Also, such color measuring devices are used to objectively and numerically characterize the various colors of the light spectrum and to insure consistency of color in a manufactured product throughout its production. Typically, high-precision color measuring devices have been of the benchtop type that are large and heavy and require connection to power mains.

More recently, portable, hand-held color measuring devices have become available that retain many of the features provided by benchtop type devices. However, such portable, hand-held devices must deal with new problems that occur due to their mobility. For example, U.S. Patent No. 5,319,437 to H. Van Aken, et al. titled HANDHELD PORTABLE SPECTROPHOTOMETER provides a spectrophotometer having a spectral analyzer and other components that deal with temperature changes and mechanical shock, in particular. The components are selectively chosen and mounted within the body of the spectrophotometer to avoid distortion caused by the differing thermal expansion rates of its materials and control the effective common points of these components.

While certain problems due to mobility may have been satisfied, some portable color measuring devices, heretofore, still fail to overcome all of the other important problems.

One problem is the undesirable change of light intensity and spectral distribution of its light source when the orientation of the device is altered. Specifically, an incandescent light source or lamp of the color measuring device typically illuminates a sample while the device takes a measurement of the sample. It is generally known that illumination of an incandescent light source is a direct function of temperature. Since the orientation of a lamp in the color measuring device affects the temperature at any given spot along its filament, the spectral emittance or color temperature of an incandescent lamp will change with orientation. As the temperature of the lamp rises, its spectral emittance alters in color.

Another problem is convenient replacement of the light source and such replacement by the user. A new light source often does not have the same overall light intensity as the light source it replaces. This difference between these outputs may increase the resultant electrical noise of the system and affect the precision and accuracy of measurements taken by the device. Typically, it is necessary to make adjustments to a portable color measuring device because of variations in light intensity and spectral distribution when the light source is replaced.

Still another problem is error due to displacement of the instrument during a measurement. Benchtop type devices are large and heavy and, thus, remain steady relative to the measured object. However, hand-held or portable color measuring devices are subject to possible sudden movements during a measurement.

Yet another problem is the difficult operation of the control buttons when the orientation of its display is altered. A portable color measuring device should be versatile enough to be used in any orientation and, likewise, have built-in displays that can be read at any orientation. Portable devices having a display that may be rotated by 90° or 180° increments are known. However, the control buttons of such devices function independently of, and are not adaptable to, the orientation of the display. In other words, the control buttons favor one position of the display over all others.

Still yet another probl m is that present portable color measuring devices may require different mechanical and optical interfaces depending on the sample being measured. Typically, this is accomplished by physically changing or shifting the internal components of the device and other manual changes to the device such as scaling factors. However, such manual changes to a color measuring device can be complicated and time-consuming for the user.

Therefore, there is a need for a portable. hand-held color measuring device that is capable of dealing with one or more of the above-noted problems. In particular, there is a need for a device that is not affected by its orientation and compensates for changes in light intensity, and "color temperature" of its light source. In addition, the device should compensate for measurement error due to displacement of the instrument, changes in display and control button orientation, and requirement for different sample interfaces. All of the above is achieved by the portable color measuring device of the present invention.

SUMMARY OF THE INVENTION

Against the foregoing background, it is a primary object of the present invention to provide a color measuring device that has a dual beam color measurement system.

It is another object of the present invention to provide such a color measuring device that may be used in any orientation without affecting the integrity of its measurement.

It is another object of the present invention to provide such a color measuring device in which the dual beam color measurement system also negates the effect of most instrument component variations, including changes in instrument orientation, temperature, power supply, lamp characteristics, detector characteristics, filter characteristics, mechanical relationships, and light level as a function of time.

It is a further object of the present invention to provide such a color measuring device in which a small integrating chamber homogenizes light source illumination to compensate for light source variations, such as changes in instrument orientation and bias, temperature, supply of power, and lamp characteristics.

It is a still further object of the present invention to provide such a color measuring device in which a programmable gain amplifier (PGA) regularizes instrument output when

the configuration of the spectrophotometer is altered and to regularize inputs to analog-to-digital converters (ADC) for improved performance.

It is still another object of the present invention to provide such a color measuring device wherein a processing circuit provides various functions required by the device due to its portability. These various functions include compensation for variations in light source intensity, color temperature, device displacement during measurements, alteration of control button position, and requirement for different sample interfaces.

To accomplish the foregoing objects and advantages, the present invention, in brief summary, comprises means for illuminating a sample, means for transmitting a reference light from the illuminating means, and means for transmitting sample light reflected from the sample. The present invention further comprises means for receiving the reference light and the sample light and for separating the reference light and the sample light into spectral components. The separating means produces reference signals and sample signals corresponding to the levels of spectral components of the reference light and the sample light, respectively. In addition, the present invention has means, responsive to the separating means, for analyzing the sample signals relative to the reference signals to provide colorimetric data. and means for outputting the colorimetric data.

The foregoing objects and advantages are also accomplished with a signal measuring device comprising means for illuminating a sample; means for transmitting light from the illuminating means to the sample and for receiving sample light from the sample;

an integration chamber interposed between the illuminating means and the transmitting means, for homogenizing the light from the illuminating means and for negating bias; means for receiving the sample light and for separating the sample light into spectral components, the separating means producing sample signals corresponding to levels of spectral components of the sample light; and means, responsive to the separating means, for analyzing the sample signals to provide colorimetric data, and for outputting the colorimetric data.

The foregoing objects and advantages are further accomplished with a signal measuring device comprising means for illuminating a sample; means for transmitting sample light reflected from the sample; means for receiving the sample light and for separating the sample light into spectral components, the separating means producing sample signals corresponding to the levels of spectrai components of the sample light; and means, responsive to the separating means, for analyzing of the sample signals. The analyzing means includes at least one programmable gain amplifier for associating a particular predetermined electrical gain level to each of the sample signals.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing, and still further, objects and advantages of the present invention will be more apparent from the following detailed explanation of the preferred embodiments of the invention in connection with the accompanying drawings:

Fig. 1 is a perspective view of the preferred embodiment of the present invention;

Fig. 2 is a simplified, diagrammatic view showing the basic internal components of the preferred embodiment of Fig. 1;

Fig. 2A is an enlarged, detailed view of the ends of the receiving fiber optic bundle and reference fiber optic bundle that are adjacent to the separator/detector means of the preferred embodiment shown in Fig. 2;

Fig. 3 is a planar top view of the detectors of the preferred embodiment of Fig. 1;

Fig. 4 is a planar top view of the filters of the preferred embodiment of Fig. 1;

Fig. 5 is a sectional view of the detectors and filters of the preferred embodiment, as shown in Figs. 3 and 4;

Fig. 6 is a schematic diagram of the main electronic processor for providing color matching data of the preferred embodiment of Fig. 1;

Fig. 7 is a flow chart of the steps executed by the processing circuit of the present invention for calibrating the present invention in preparation for measuring a sample;

Fig. 8 is a flow chart of the steps executed by the processing circuit for measuring a sample;

Fig. 9 is a graphical representation of an array of narrow-band spectrally selective filters vs. light spectrum range (in nanometers) for a multi-filter color measuring device;

Fig. 10 is an enlarged view of the instrument display and control buttons of the preferred embodiment of Fig. 1; and

Fig. 11 is another view of the instrument display and control buttons shown in Fig. 7, wherein the orientation of the display and buttons have been rotated clockwise by 90°.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawings and, in particular, to Fig. 1, there is provided a portable, hand-held high precision color measuring device which is generally represented by reference numeral 10. The following description of the preferred embodiment refers to a spectrophotometer as the color measuring device 10, however it should be understood that the present invention may be applied to a wide-variety of signal measuring devices or color measuring devices, such as colorimeters, spectrocolorimeters, radiometers and spectroradiometers, and is not restricted to spectrophotometers.

The spectrophotometer 10 of the present invention is a high precision instrument for the measurement of object color of non-self-luminous objects. For its portability, the spectrophotometer 10 is battery-powered and functionally designed to be held in one hand and, thus, fit comfortably between one's thumb and forehand. The spectrophotometer 10 may be held horizontally, vertically or in angular position, provided its lower end 14 is adjacent to an object 12, or a portion thereof, that is to be measured. Referring to Fig. 1, the lower end 14 of the spectrophotometer 10 is shown vertically above, and adjacent to, the object 12 that is to be measured.

The color measurement process is controlled by manipulating one or more control buttons 16 on a front panel 18 of the spectrophotometer 10. The process is executed by pressing an Execute button on the rear panel (not shown) of the spectrophotometer 10. The results of the process appear on an instrument display 20, such as a liquid crystal

display or a computer screen. The color measurement process is described in detail below. In addition, the rear panel is easily removable from the rest of the spectrophotometer 10 in order to gain access to the inside of the spectrophotometer. Such access is necessary in order to change the power source or the light source, or other maintenance purposes.

Referring to Fig. 2, there is shown a diagrammatic view showing the basic internal components or elements of the preferred embodiment. The body of the spectrophotometer 10 is represented by reference numeral 22.

The light source 24 of the spectrophotometer 10 is shown as an incandescent light bulb. The type of light source 24 used in a spectrophotometer is unimportant provided it has sufficient energy for all desired wavelengths to be measured. The most common types of light sources 24 used for spectrophotometers are tungsten and xenon, and in some cases, light emitting diodes. For the preferred embodiment, the light source 24 is a gas-filled tungsten lamp, operated in a constant current mode. The advantages of a tungsten lamp include a broad-band smooth radiator across the visible spectrum, stable performance and well-defined operating characteristics.

Generally, since the measurement is a direct function of the light intensity of the light source 24, the light source must be very stable and precisely controlled. However, the dual beam system of the present invention, described below, compensates for any variations produced by the light source 24, whether spectral or photometric.

The dual beam system shown in Fig. 2 provides the highest precision and certainty. The dual beam system monitors the light source 24 so that color measurements are relative rather than absolute as in prior systems. In other words, one beam of the dual beam system is the reference to the other beam. In the present dual beam system, the receiving fiber optic bundle 40 transmits a signal that is analyzed relative to a signal conveyed by the reference fiber optic bundle 44. Thus, if the light source current changes during the measurement or the spectrophotometer 10 changes its measurement capability over time, the resulting data still remain accurate. In addition, the parallel configuration of a dual beam system shown in Fig. 2 improves performance speeds.

Also, the lamp or light source is turned on only for the measurement in order to minimize power consumption, i.e., conserve battery life. However, a light source, and an incandescent lamp in particular, requires a sufficient amount of time to stabilize. During this period, its emittance is changing and at any wavelength non-uniformly for color and output. Use of the dual beam system of the present invention negates this problem.

As shown in Fig. 2, the illuminating and receiving fiber optic bundles 28, 40 form the first beam of the dual beam system. The illumination of the light source 24 is directed towards a light receiving end 26 of a light conveying or illuminating fiber optic bundle 28. At least one conveying end 30 is located at another end of the illuminating fiber optic bundle 28 opposite the light receiving end 26.

Th illuminating fiber optic bundle 28 has a plurality of equally divided conveying ends 30, f ur of which are shown in Fig. 2. The fibers of each conveying end 30 are well distributed and randomized so that the illumination is uniform and representative of the light source 24.

In a preferred embodiment, there are six conveying ends. The six conveying ends 30 are arranged to illuminate a sample 32 at 45° from the normal viewing axis 34. The sample 32 is representative of any type of surface to be measured by the spectrophotometer 10. Each conveying end 30 is separated from the other conveying ends in order to provide circumferential illumination of the sample 32. In the most preferred embodiment, there are six conveying ends 30 that are equally separated from each other by 60° in azimuth. This configuration has been found to provide proper and complete measurements of textured, directional and/or non-uniform samples.

The geometry of the illuminating and receiving fiber optic bundles 28, 40 relative to the sample 32 must be designed to accommodate the various objects or samples to be measured. Such object variances include size, shape, and texture, as well as color. Thus, the interface between the spectrophotometer 10 and the measured object or sample 32 is extremely important. Therefore, spectrophotometer 10 must be capable of measuring object color without destroying or modifying the sample 32.

There are two common instrument geometries for color measurement: 45/0 and d/0. 45/0 can be 0/45, and d/0 can be 0/d by the law of reciprocity, and d/0 or 0/d can

effectively mean d/8 or 8/d. Although other geometries are used, their specific descriptions are not necessary for a full and accurate understanding of the present invention. However, it should be understood that the references specifically to the 45/0 geometry herein also contemplate the use of these other geometries.

For the 45/0 geometry, illumination is at 45° from the normal viewing axis 34 to the sample 32. The illumination can be a single beam, or multiple beams azimuthally separated (as shown in Fig. 2) or forming a continuous ring.

Light reflected from the sample 32 is collected through a lens or lens system 36 located above the sample. This reflected or sample light along the normal view axis 34 is directed by the lens system 36 to a receiving end 38 of a receiving fiber optic bundle 40. A distal end 42 opposite the receiving end 38 of the receiving fiber optic bundle 40 has a flared shape and is attached to a separator/detector means 50 as discussed below.

In addition to the illuminating and receiving fiber optic bundles 28, 40, which form the first beam of the dual beam system, a reference fiber optic bundle 44 forms part of the second beam. The reference fiber optic bundle 44 transmits illumination from the light source 24 at one end 46 to the separator/detector means 50 at the other, flared end 48. Thus, the reference fiber optic bundle 44 bypasses the sample 32 and sends illumination information directly to the separator/detector means 50.

The illuminating fiber optic bundle 28 and the reference bundle 44 are, preferably, illuminated through an infrared absorbing glass filter 51. The separator/detector means 50 (and in particular, the silicon detector array 52) is sensitive to infrared light. Also, illumination from the light may cause the temperature of the sample 32 to increase to undesirable levels. The filter 51 adjusts the illumination from light source 24 to accommodate the separator/detector means 50 and the sample 32.

Most fibers of the first beam, i.e., illuminating and reference fiber optic bundles 28, 44, serve to illuminate the sample 32. For the preferred embodiment, approximately 30% fiber optic bundles go to the reference detectors 56.

The present invention is essentially unaffected by instrument orientation. In other words, it can be used in any orientation without affecting the integrity of the measurement. Most problems caused by changing instrument orientation are negated by use of the present dual beam system. However, orientation bias may possibly occur due to the finite size of the fibers, imperfect mixing and high precision of the measurements. To negate this bias, a small integrating chamber 92 is interposed between the light source 24 and the illuminating and reference fiber optic bundles 28, 44. This small integrating chamber 92, made of or coated with a highly reflective white material, homogenizes the illumination from the light source 24 since it collects and redistributes the light over all angles, and the homogenized light is what illuminates the illuminating and reference fiber optic bundles 28, 44.

Referring to Fig. 2A, the distal end 42 of the receiving fiber optic bundle 40 is separated into a plurality of individual fiber bundles 43. Each individual fiber bundle 43 represents geometrically, as well as qualitatively and quantitatively, the light received by the receiving end 38 of the receiving fiber optic bundle 40. The number of individual fiber bundles 43 corresponds to the number of sample detectors 54 situated within the separator/detector means 50. In the preferred embodiment, the distal end 42 has sixteen individual fiber bundles 43. In addition, the number of fibers (not shown) within each individual fiber bundle 43 may vary, however it is preferred that each fiber bundle have the same number of fibers.

Similar to the receiving fiber optic bundle 40, the reference fiber optic bundle 44 is separated into a plurality of individual fibers bundles 49. The number of fiber bundles 49 should equal the number of reference detectors 56. Preferably, sixteen individual fiber bundles 49 are present for flared end 48. Each individual fiber bundle 49 may vary in the number of fibers at its flared end 48, however the number of fibers in all individual fiber bundles 49 should be the same in any given spectrophotometer 10.

In this manner, each individual fiber bundle 43, 49 of the receiving and reference fiber optic bundles 40, 44 are directed toward an individual filter and detector combination of the separator/detector means 50.

Generally, the type of detector used in a spectrophotometer is unimportant provided it has sufficient sensitivity across the entire visible spectrum. For the preferred

embodiment, a silicon type detector is used. Silicon type detectors are solid state devices generally operated in a current or short circuit mode. However, silicon type detectors are more sensitive to infrared energy than visible energy. Therefore, provision must be made to block infrared light from getting to the detector. Also, silicon type detectors can be sensitive to temperature such that output changes as a function of temperature.

Referring to Fig. 3, the separator/detector means 50 (of Fig. 2) comprises a detector array 52 that has thirty-two individual detectors of the type described as planar-passivated detectors. It is preferred that the detector array 52 be a single piece of silicon. The detector array 52 is arranged as a row of sample detectors 54 positioned parallel to a row of reference detectors 56. Since the individual detectors 66, 68 of the detector array 52 are, preferably, created on the same silicon wafer and are in close proximity to each other, they will generally respond equally to temperature and other environmental effects. The row of sample detectors 54 receives energy from the receiving fiber optic bundle 40, whereas the row of reference detectors 56 receives energy from the reference fiber optic bundle 44.

A spectrophotometer 10 relies on some type of device to separate white light into its constituent wavelengths. Although the present invention may utilize other spectral separators, such as a grating system, the preferred embodiment uses a filter system due to its compact lightweight, relatively inexpensive design and substantially alignment free maintenance. The spectral region covered by the preferred embodiment is 390 to 710 nanometers (nm), using sixteen filters each having a nominal half-power bandwidth of 20

nm. Although the human eye can perceive energy beyond this region, this range is considered completely adequate for the purpose of color measurement and is the region most widely used by color measuring devices. Any color filter is subject to deviation from design specification and variability in such areas as bandwidth, center wavelength, transmission, cut-on and cut-off. To achieve better accuracy and reproducibility with filter systems, mathematical corrections routines are employed by the preferred embodiment.

A spectrophotometer utilizing a filter system can operate by a serial method or a parallel method. For the serial method, each of a plurality of filters is individually and consecutively interposed within a beam of light directed toward a single detector. The parallel method uses a plurality of filters over an array of detectors. The filters used are generally of the dichroic or interference type. The latter is usually technically superior, but more expensive. These methods or techniques can yield filters with steep slopes and narrow bands, as shown in Fig. 9. Interference filters can be less sensitive to temperature and more durable than dichroics. In particular for dichroics, temperature can affect the slopes and bandpasses of the filters, thereby yielding an unstable system. The preferred embodiment utilizes interference filters and, thus, is very temperature stable.

Referring to Fig. 4, the separator/detector means 50, shown in Fig. 2, also includes a spectral separator that comprises an array of interference filters 58 mounted and sealed to a mechanical frame 60. Interference filters 58 of the type used in the preferred embodiment are not affected significantly by temperature, i.e., do not characteristically or physically change as a function of temperature. Such temperature independent filters may

help to avoid measurement error, such as altering color or spectral wavelength, due to temperature variations in the environment where the spectrophotomet r 10 is used. Although the dual beam system described above can compensate for some temperature variations. it can not compensate for a wavelength shift of a particular filter. Thus, the use of such filters or components will assure improved measurement precision over a range of temperatures where a portable color measuring device would be used.

The mechanical frame 60 is also bonded and sealed directly to the silicon surface outside the active areas of the detector array 52. Like the detector array 52, the interference filter array 58 has a row for the sample filters 62 positioned parallel to a row of reference filters 64. The mechanical frame 60 positions the arrays 52, 58 so that the interference filter array is located directly adjacent to, but is optically isolated from, the detector array, as shown in Fig. 5. In this manner, each individual sample detector 66 is immediately adjacent its corresponding sample interference filter 70 having the same wavelength. Likewise, each individual reference detector 68 is immediately adjacent to its corresponding reference interference filter 72. The individual sample 70 and reference 72 interference filters are separated from each other and are terminated in the mechanical frame 60 so that one fiber bundle illuminates one, and only one, filter/detector combination. Sealing the frame 60 to the silicon surface also protects the detector surface from harmful effects of contamination.

Referring to Fig. 6, substantially all instrument operations are controlled by a processor or computer 74, such as an internal central processing unit. The circuitry for the

spectrophotometer 10 comprises dedicated sections intended to control functions such as power consumption, signal conditioning, and user interface controls. In addition, the computer 74 provides various functions required by the spectrophotometer 10 due to its portability. For example, the computer 74 determines whether a measurement error has occurred due to extraneous movement of the spectrophotometer 10 during a measurement. Such extraneous movement is possible because of the portable, hand-held nature of the spectrophotometer 10. The computer 74 takes multiple measurements or scans of the sample 32 and compares the scans to each other. If one or more scans are different by a preset amount, the computer 74 instructs the instrument display 20 to caution the user that an invalid measurement may have been made.

Preferably, the computer 74 and its various interconnected components are located on one or more circuit boards of the spectrophotometer 10. When using a plurality of circuit boards, the various components are separated to separate planar surfaces, yet remain interconnected. In the preferred embodiment, several of the components are located on the second circuit board 77 situated parallel to, and behind, the first circuit board 75.

Each of the thirty-two individual detectors 54, 56 described above is directly connected to its own amplifier 76, 78: sixteen to the sample detectors and sixteen to the reference detectors. Then, the entire spectrum, i.e., the sixteen sample signals (1) through (16) and sixteen reference signals (1) through (16), for reference over the region 390 nm to 710 nm, are measured and evaluated simultaneously by the scan rate of a pair f

multiplexers or Mux's 80, 82. Each Mux 80, 82 which is controlled by the computer 74 via control lines 77, serially addresses each amplifier 76, 78, respectively.

The Mux's 80, 82 additionally address other channels or signals, such as signals (17) through (23) that are received through inputs 81 as shown in Fig. 6, that control various functions of the spectrophotometer 10. For example, such signals include ground, temperature, LCD contrast voltage, +12 volts, -12 volts, battery voltage and lamp current information, and are received by the reference Mux 82 through inputs 81. Each of the inputs 81 is connected to another part of the circuitry of the circuit boards 75, 77 or a separate physical device, such as device 83 which can sense ambient temperature as shown in Fig. 6. These other signals (17) through (23) may be sent through the Mux's 80, 82 along with the sixteen sample signals and sixteen reference signals, described above, for eventual processing by computer 74.

The channels or signals addressed by the Mux's 80, 82 may be read in any order so long as sufficient data is supplied to the computer 74, as necessary. For example, during a measurement cycle of the spectrophotometer 10, Mux 82 may first read the signal that corresponds to the battery voltage in order to make sure that there is sufficient voltage to power the light source 24. Then, signals (1) through (16) for both the sample side and reference side are serially addressed through the Mux's 80, 82. Thereafter, the Mux may read the other signals, such as the LCD contrast voltage, +12 volts, -12 volts and lamp current, on a routine or periodic basis. In addition, a single measurement cycle may allow

for repeated measurements in order to compare the measurements against each other to determine their validity and to provide an averaging function to minimize electrical noise.

Each amplifier output of the amplifiers 76, 78 is directed in turn by the Mux's 80, 82 to one of two programmable gain amplifiers (PGA's) 84, 86, and then, to a corresponding analog-to-digital converter (ADC's) 88, 90. Once digitized, the output signals of the ADC's 88, 90 are directed to the computer 74.

The PGA's 84, 86 are commanded by the computer 74 to associate a particular channel with a particular pre-determined electrical gain or multiplier. In this manner, a uniform signal level is provided to the ADC's 88, 90, which perform best when they work over the same dynamic range for the signals. The output of the light source 24, the sensitivities of the detectors 52, the transmittances of the filters 58 and the spectral selectivities of the system's various components, each can vary on a wavelength basis. Therefore, every channel may have a different signal level even with a uniformly, reflecting sample. Also, spectrophotometers 10 will vary from one to another in terms of their overall signal levels. The PGA's 84, 86 give a user a simple and convenient way to regularize the signals fed into the ADC's 88. 90. If a light source 24 is changed, there can be differences in output from one light source to another. The PGA's 84, 86 provide a way for a user to reset the spectrophotometer 10, for example, by modifying software accessed by the computer 74, to adapt to light source changes.

The PGA's may also allow for higher precision because of higher signal to noise ratios. For example, signals from the amplifiers might range from, for example, about 0 to about 10 volts, which might represent reflectance values of 0 to 100%. These signals are fed to the ADC's. The output of an ADC is in terms of digital counts, and could range from, for example, about 0 to about 65.536 counts for a 0 to 10 volt input, with an uncertainty of about ±1 count. For simplicity and discussion purposes, we shall assume that the ADC has an uncertainty of about 1%. The following signals would then be converted as follows:

Signal in	ADC output in %	Uncertainty
10 volts	99 to 101%	1%
9 volts	89 to 91%	1.1%
8 volts	79 to 81%	1.25%
2 volts	19 to 21%	5%
1 volt	9 to 11%	10%

Pure white samples might yield signals of 10 volts. Very dark or black samples might yield signals closer to 0 volts. Based on the above, a red sample would have signals that varies by wavelength from about zero to about 8 volts. As shown in the table, there would be non-uniform uncertainty based on signal level at different wavelengths.

To improve the precision or level of uncertainty, the following technique could be employed. An initial measurement is taken and temporarily stored as signal values. At

each wavelength, a determination is made as to which predetermined signal interval the measured signal corresponds. For example, if there are 10 intervals of the total signal level, i.e., 0 to 1, 1 to 2, ..., 9 to 10 and the measured signal falls into the first interval, the PGA would be commanded to multiply subsequent measured signals at that wavelength by 10, the 2nd interval by 5, the 10th interval by 1. Of course, the number of intervals may vary. Now, based on the above example, the uncertainty for each interval is 1%.

Signal in	ADC output in %	Uncertainty
10 volts x 1	99 to 101%	1%
9 volts x 1.1	99 to 101%	1%
8 volts x 1.23	99 to 101%	1%
2 volts x 5	99 to 101%	1%
1 volt x 10	99 to 101%	1%

The computer 74 would mathematically divide the values by the previous multiplier.

The computer 74 also provides the standardization function which scales the output signals to the proper photometric level. Upon completing the standardization function, the computer 74 operates on scaled numbers to compute a variety of different color scales and functions. The computer 74 further performs other functions, such as interpreting the operations of all the control buttons 16, writing to the display 20,

communicating with such external devices. and monitoring all internal functions and provides control or warnings as appropriate.

Another essential function of the computer 74 is to perform mathematical correction of the measured data, i.e., the calibration function. Ideally, each filter of the interference filter array 58 produces an output signal in the form of a square wave within a particular portion of the spectrum (as shown in Fig. 9), but, in reality, their transmittance curves look more like high order sine waves. Also, an error free signal is difficult to achieve because of a number of technical considerations. These wavelength errors cannot be completely eliminated by the filters due to manufacturing and instrument variations as well. Also, it is more economical to mathematically correct these functions than impose stringent and costly specifications on the system elements. The computer 74 of the preferred embodiment utilizes a process that entails measuring a series of known color tiles. For a particular instrument, the raw data for each of the tiles at each wavelength are processed by a particular math model and a set of correction coefficients are determined. These coefficients are stored within the spectrophotometer's memory, within the computer 74, and are used to improve the spectrophotometer's accuracy and inter-instrument agreement.

The logic in the computer 74 used to calibrate and measure the data is shown in Figs. 7 and 8. First, to calibrate or standardize the spectrophotometer 10, the area of view (AOV) is read and the measurement limits obtained, shown by steps 110 and 112. Then, the user is prompted to prepare for a black reading, shown by step 114. Once preparations

for the black reading are made, the computer 74 reads the black reading and determines whether the reading is in error, shown by steps 116 and 118. If an error occurs, the user or the computer 74 may determine whether to perform another black reading, shown by step 120. After a satisfactory black reading is obtained, the user is prompted to prepare for a white reading and, thereafter, a white reading is made, shown by steps 122 and 124. Like the black reading, the user or computer 74 may decide

to perform another white reading if an error occurs while the white reading is taken, shown by steps 126 and 128.

Once satisfactory black and white readings are obtained by computer 74, the computer 74 calculates the coefficients that may be used for other functions of the spectrophotometer 10, shown by step 130. These coefficients include data for the black and white tiles on a wavelength basis, time/date information, temperature information and area of view (AOV). The derived coefficients are stored in the memory portion of the computer 74 upon their determination, shown by step 132.

Subsequent to calibrating the spectrophotometer 10, data for the sample 32 may be obtained. To measure the data for the sample 32, the computer 74 initially determines whether the spectrophotometer 10 needs to be calibrated again. First, the computer 74 determines the present time, shown by step 136. Then, the computer 74 determines whether a certain, predetermined period of time selectable by the user has gone by since the last calibration, whether the area of view has changed, and whether the temperature has changed beyond a preset temperature limit, shown by steps 138, 140 and 142 respectively. If any of these determinations produces an affirmative result, the computer 74 will prompt the user on display 20 to repeat the calibration process described above, shown by steps 144, 146 and 148. However, if not much time has gone by since the last calibration, and the area of view and temperature have not changed significantly, the remaining steps of the sample measurement process are executed as described below.

After determining that another calibration is not necessary, the computer 74 obtains the calibration data stored in its memory portion, shown by step 150. Then, the computer 74 checks to make sure that a preset time, preferably 5 seconds, has elapsed since the last measurement and that the batteries are not low in power, shown by steps 152 and 154.

Thereafter, the actual measurement process of the computer 74 begins by acquiring raw data for the sample 32 by the dual beam system described above, shown by steps 158 and 160. Of course, if an error occurs during the acquisition of the raw data, the computer 74 will notify the user on the display 20, shown in steps 162 and 164, and further, the computer 74 will notify the user to prepare to acquire another set of raw data for the sample 32. Then, the data are checked for validity. If the computer 74 determines that the measurement is questionable based on comparing the individual channel data from each measurement cycle, the computer will ask the user whether the user wishes to accept the data as taken or to acquire new raw data, shown by steps 166 and 170. Next, the computer 74 determines whether any of the data are too high or too low, shown by steps 166 and 172. Next, the light off data are subtracted from the light on data, shown by step 174. Thereafter, the data are adjusted photometrically and corrected spectrally, shown by steps 176 and 178. Once satisfactory data for the sample 32 are determined, the time and date of the measurement are recorded, shown by step 180. Finally, light booth and scale/index calculations are performed on the newly determined data, shown by steps 182 and 184. Also, the data will be subsequently shown on the display 20 for viewing by the user, shown by step 186.

As described above, the raw data for the sample 32 is acquired by the dual beam system described above, shown by step 158 of Fig. 8. During step 158, two sub-steps occur. First, the sample and reference data are acquired through the dual beam system while the light source 24 is off. Second, the sample and reference data are again acquired, this time while the light source 24 is on. For each of these sub-steps, the sample and reference data may be acquired consecutively. However, it is preferred that the sample and reference data be acquired simultaneously, as permitted by the dual Mux-configuration of the electronic circuits as shown in Fig. 6. Thereafter, the difference between the light on sample data and the light off sample data is divided by the difference between the light on reference data and the light off reference data, as represented by step 174. Therefore, steps shown in Fig. 8 provide the process necessary to control the dual beam system of the preferred embodiment. The sequence and number of steps shown for the processes of standardization and measurement for the preferred embodiment can, of course, be alterered, rearranged or augmented in order to suit other measurement needs.

Tables that illustrate qualitatively the improvement gained by the above-described process are as follows.

Pale Gray:

Wavelength	Target	Uncorrected	Uncorrected - Target	Corrected	Corrected - Target
400 nm	58.44	58.03	-0.41	58.47	0.03
420 nm	60.26	59.72	-0.54	60.30	0.04
440 nm	61.29	60.81	-0.48	61.29	0.00
460 nm	61.86	61.52	-0.34	61.99	0.13
480 nm	62.05	61.79	-0.26	62.19	0.14
500 nm	62.17	61.96	-0.21	62.37	0.20
520 nm	62.23	62.03	-0.20	62.43	0.20
540 nm	62.19	62.04	-0.15	62.37	0.18
560 nm	61.92	61.73	-0.19	62.15	0.23
580 nm	61.59	61.39	-0.20	61.86	0.27
600 nm	61.67	61.45	-0.22	61.76	0.09
620 nm	61.82	61.58	-0.24	61.74	-0.08
640 nm	61.80	61.42	-0.38	61.84	0.04
660 nm	61.75	61.58	-0.17	61.80	0.05
680 nm	61.92	61.74	-0.18	61.89	-0.03
700 nm	62.12	61.99	-0.13	62.12	0.00
		Std Dev	0.12		0.10

Mid Gray:

Wavelength	Target	Uncorrected	Uncorrected - Target	Corrected	Corrected - Target
400 nm	20.88	20.70	-0.18	20.90	0.02
420 nm	22.48	22.11	-0.37	22.46	-0.02
440 nm	23.54	23.17	-0.37	23.51	-0.03
460 nm	24.02	23.78	-0.24	24.01	-0.01
480 nm	24.04	23.91	-0.13	24.06	0.02
500 nm	24.00	23.86	-0.14	24.01	0.01
520 nm	23.98	23.80	-0.18	23.94	-0.04
540 nm	23.96	23.79	-0.17	23.92	-0.04
560 nm	23.78	23.68	-0.10	23.82	0.04
580 nm	23.58	23.45	-0.13	23.63	0.05
600 nm	23.74	23.51	-0.23	23.65	-0.09
620 nm	23.93	23.71	-0.22	23.83	-0.10
640 nm	23.88	23.67	-0.21	23.84	-0.04
660 nm	23.71	23.60	-0.11	23.66	-0.05
680 nm	23.78	23.62	-0.16	23.67	-0.11
700 nm	23.92	23.72	-0.20	23.79	-0.13
		Std D v	0.08		0.05

Deep Gray:

Wavelength	Target	Uncorrected	Uncorrected - Target	Corrected	Corrected - Target
400 nm	4.72	4.64	-0.08	4.67	-0.05
420 nm	4.70	4.59	-0.11	4.61	-0.09
440 nm	4.67	4.67	0.00	4.70	0.03
460 nm	4.67	4.61	-0.06	4.63	-0.04
480 nm	4.67	4.63	-0.04	4.66	-0.01
500 nm	4.66	4.63	-0.03	4.65	-0.01
520 nm	4.75	4.72	-0.03	4.76	0.01
540 nm	4.93	4.84	-0.09	4.88	-0.05
560 nm	4.92	4.89	-0.03	4.90	-0.02
580 nm	4.75	4.72	-0.03	4.74	-0.01
600 nm	4.64	4.61	-0.03	4.62	-0.02
620 nm	4.68	4.58	-0.10	4.58	-0.10
640 nm	4.87	4.81	-0.06	4.91	0.04
660 nm	5.03	4.94	-0.09	4.99	-0.04
680 nm	5.89	5.61	-0.28	5.86	-0.03
700 nm	7.91	7.10	-0.81	8.06	0.15
		Std Dev	0.07		0.04

Deep Pink:

Wavelength	Target	Uncorrected	Uncorrected - Target	Corrected	Corrected - Target
400 nm	14.01	13.98	-0.03	14.01	0.00
420 nm	12.46	12.69	0.23	12.50	0.04
440 nm	10.44	10.93	0.49	10.51	0.07
460 nm	8.62	8.98	0.36	8.67	0.05
480 nm	7.25	7.62	0.37	7.29	0.04
500 nm	6.43	6.59	0.16	6.50	0.07
520 nm	6.26	6.37	0.11	6.39	0.13
540 nm	7.01	6.97	-0.04	7.16	0.15
560 nm	8.85	8.62	-0.23	9.25	0.40
580 nm	12.07	11.81	-0.26	12.30	0.23
600 nm	17.23	16.05	-1.18	17.43	0.20
620 nm	24.06	22.07	-1.99	24.33	0.27
640 nm	31.64	29.51	-2.13	31.67	0.03
660 nm	38.86	37.13	-1.73	38.90	0.04
680 nm	45.01	43.44	-1.57	44.93	-0.08
700 nm	49.24	47.69	-1.55	49.28	0.04
		Std Dev	0.95		0.12

Red:

Wavelength	Target	Uncorrected	Uncorrected - Target	Corrected	Corrected - Target
400 nm	1.02	1.03	0.01	1.03	0.01
420 nm	1.10	1.05	-0.05	1.07	-0.03
440 nm	1.17	1.18	0.01	1.21	0.04
460 nm	1.24	1.22	-0.02	1.23	-0.01
480 nm	1.34	1.33	-0.01	1.36	0.02
500 nm	1.45	1.43	-0.02	1.45	0.00
520 nm	1.71	1.66	-0.05	1.71	0.00
540 nm	2.19	2.09	-0.10	2.16	-0.03
560 nm	2.63	2.53	-0.10	2.86	0.23
580 nm	4.82	4.41	-0.41	4.79	-0.03
600 nm	17.05	13.35	-3.70	16.99	-0.06
620 nm	39.16	32.11	-7.05	39.01	-0.15
640 nm	54.51	49.45	-5.06	54.50	-0.01
660 nm	62.23	59.80	-2.43	62.21	-0.02
680 nm	66.49	65.32	-1.17	66.60	0.11
700 nm	69.24	68.28	-0.96	69.07	-0.17
		Std Dev	**2.23**		**0.08**

Orange:

Wavelength	Target	Uncorrected	Uncorrected - Target	Corrected	Corrected - Target
400 nm	5.27	5.11	-0.16	5.14	-0.13
420 nm	5.36	5.14	-0.22	5.19	-0.17
440 nm	5.44	5.36	-0.08	5.42	-0.02
460 nm	5.54	5.36	-0.18	5.40	-0.14
480 nm	5.66	5.49	-0.17	5.56	-0.10
500 nm	5.95	5.76	-0.19	5.80	-0.15
520 nm	6.87	6.56	-0.31	6.77	-0.10
540 nm	12.03	10.09	-1.94	11.99	-0.04
560 nm	38.68	33.43	-5.25	38.54	-0.14
580 nm	61.34	58.18	-3.16	61.35	0.01
600 nm	68.99	66.94	-2.05	68.87	-0.12
620 nm	72.79	71.23	-1.56	72.91	0.12
640 nm	74.92	73.65	-1.27	74.85	-0.07
660 nm	76.74	75.92	-0.82	76.65	-0.09
680 nm	78.82	78.12	-0.70	78.79	-0.03
700 nm	80.66	80.04	-0.62	80.90	0.24
		Std Dev	**1.40**		**0.11**

Yellow:

Wavelength	Target	Uncorrected	Uncorrected - Target	Corrected	C rrected - Target
400 nm	1.82	1.78	-0.04	1.79	-0.03
420 nm	2.19	2.01	-0.18	2.11	-0.08
440 nm	3.18	2.91	-0.27	3.21	0.03
460 nm	5.81	5.12	-0.69	5.83	0.02
480 nm	13.19	11.12	-2.07	13.19	0.00
500 nm	30.55	28.81	-1.74	30.45	-0.10
520 nm	53.73	50.00	-3.73	53.62	-0.11
540 nm	67.74	65.72	-2.02	67.64	-0.10
560 nm	73.57	72.23	-1.34	73.49	-0.08
580 nm	76.11	74.89	-1.22	75.83	-0.28
600 nm	78.40	77.54	-0.86	78.46	0.06
620 nm	80.13	79.35	-0.78	80.15	0.02
640 nm	81.09	80.28	-0.81	81.14	0.05
660 nm	81.83	81.40	-0.43	81.89	0.06
680 nm	82.53	82.24	-0.29	82.57	0.04
700 nm	83.17	82.84	-0.33	83.04	-0.13
		Std Dev	0.98		0.09

Green:

Wavelength	Target	Uncorrected	Uncorrected - Target	Corrected	Corrected - Target
400 nm	6.70	6.55	-0.15	6.62	-0.08
420 nm	7.68	7.39	-0.29	7.62	-0.06
440 nm	9.28	8.79	-0.49	9.24	-0.04
460 nm	12.61	11.70	-0.91	12.54	-0.07
480 nm	19.56	17.61	-1.95	19.46	-0.10
500 nm	28.97	27.65	-1.32	29.02	0.05
520 nm	31.09	30.64	-0.45	31.18	0.09
540 nm	25.01	25.63	0.62	24.98	-0.03
560 nm	18.49	19.07	0.58	18.21	-0.28
580 nm	14.07	14.38	0.31	13.97	-0.10
600 nm	11.44	11.80	0.36	11.35	-0.09
620 nm	10.08	10.32	0.24	9.81	-0.27
640 nm	9.63	9.68	0.05	9.56	-0.07
660 nm	9.99	9.89	-0.10	9.97	-0.02
680 nm	11.23	10.88	-0.35	11.22	-0.01
700 nm	13.50	12.61	-0.89	13.67	0.17
		Std Dev	0.70		0.11

Cyan:

Wavelength	Target	Unc rrected	Uncorrected - Target	Corrected	Corrected - Target
400 nm	25.59	25.08	-0.51	25.59	0.00
420 nm	32.78	31.57	-1.21	32.80	0.02
440 nm	38.29	36.88	-1.41	38.31	0.02
460 nm	41.81	40.83	-0.98	41.67	-0.14
480 nm	41.94	41.54	-0.40	41.79	-0.15
500 nm	37.34	37.10	-0.24	37.06	-0.28
520 nm	28.84	29.58	0.74	28.55	-0.29
540 nm	20.35	21.09	0.74	20.18	-0.17
560 nm	14.13	14.69	0.56	13.92	-0.21
580 nm	10.30	10.77	0.47	10.42	0.12
600 nm	8.12	8.39	0.27	7.98	-0.14
620 nm	7.00	7.20	0.20	6.79	-0.21
640 nm	6.63	6.67	0.04	6.57	-0.06
660 nm	6.91	6.87	-0.04	6.94	0.03
680 nm	7.93	7.61	-0.32	7.88	-0.05
700 nm	9.81	9.08	-0.73	10.00	0.19
		Std Dev	0.68		0.12

Deep Blue:

Wavelength	Target	Uncorrected	Uncorrected - Target	Corrected	Corrected - Target
400 nm	12.55	12.35	-0.20	12.51	-0.04
420 nm	12.56	12.63	0.07	12.50	-0.06
440 nm	8.94	9.68	0.74	8.91	-0.03
460 nm	4.76	5.35	0.59	4.60	-0.16
480 nm	2.21	2.63	0.42	1.95	-0.26
500 nm	1.33	1.38	0.05	1.23	-0.10
520 nm	1.04	1.09	0.05	1.05	0.01
540 nm	1.08	1.04	-0.04	1.04	-0.04
560 nm	0.98	1.01	0.03	0.97	-0.01
580 nm	0.67	0.73	0.06	0.71	0.04
600 nm	0.61	0.58	-0.03	0.56	-0.05
620 nm	0.64	0.58	-0.06	0.59	-0.05
640 nm	0.65	0.63	-0.02	0.65	0.00
660 nm	0.76	0.73	-0.03	0.75	-0.01
680 nm	1.49	1.21	-0.28	1.57	0.08
700 nm	6.37	4.05	-2.32	6.07	-0.30
		Std Dev	0.66		0.10

As described above, the light source 24 is energized only for the color measurement process in order to conserve power. When energized, the current applied to the light source 24 is monitored by the dual beam color measurement system, and maintained at a constant level to insure illumination stability. The light source 24 will illuminate for a fixed period of time during which a measurement is made by pressing the Execute button on the rear panel. This illumination process is performed in two stages that are controlled by the processor or computer 74. First, the light source 24 is given a high current in order to warm the light source. Second, a nominal current is fed to the light source 24 during data acquisition, i.e., color measurement. Thereafter, the light source will be de-energized. By the two stage illumination, and again by the de-energization, the illumination time period of the light source 24 is minimized in order to conserve power.

The computer 74 controls the amount of power that is consumed by way of shutting off circuitry that is not in use. The power scheme is set up so that there are three modes of power down. Mode one is an awake mode in which all circuitry except for the analog board is on, the analog board is only turned on during a measurement. Mode two slows down the microprocessor and this mode is the normal mode of operation when the instrument is not in use. This scheme allows the computer 74 to keep a battery charge for an extended period of time.

In addition, the computer 74 monitors the internal state of the spectrophotometer 10 as well as its configuration and includes functions such as area of view or other

configuration, temperature sensing, maintenance of non-volatile memory, and sensing low battery conditions.

Referring to Figs. 10 and 11, the instrument display 20 and control buttons 16, as well as the rest of the portable spectrophotometer 10, may be used in any orientation, including the two orientations shown. The four control buttons 16 are marked, preferably, as arrow or cursor keys that are positioned in a cross-shaped pattern near the display 20. None of the control buttons 16 have markings or indications other than the generic arrows shown in Figs. 10 and 11.

Fig. 10 shows one view by a user of the spectrophotometer 10, wherein the instrument display 20 is seen above the control buttons 16. For this view, the data shown on the display 20 is oriented appropriately, i.e., from left to right from the user's view. Also for this view, the four control buttons 92, 94, 96 & 98 correspond to directions or movements on the display 20 such that the control button referenced by numeral 92 is the left control button.

Fig. 11 shows a different view by a user of the spectrophotometer 10. The orientation of the spectrophotometer 10 has been rotated counter-clockwise by 90° and, thus, the control buttons 16 are now to the right of the instrument display 20 as viewed by the user. In order to retain the ease of reading the data on the display 20 (from left to right), the contents of the display, such as the data, have been rotated clockwise by 90°. Although the positions of the control buttons 16 have not been changed, they have been

reoriented or reprogrammed to correspond to new directions or movements relative to the display 20. For example, the control button reference by numeral 92 is no longer the left control button and becomes the down control button. The left control button is now referenced by numeral 94.

In the present invention, a variety of sample interface devices, such as a removable nose-cone 100 (shown in Fig. 2), may be easily installed by a user in order to change the optics of the system, or a portion thereof. The sample interface devices may accommodate a change in the size of the actual area measured by the spectrophotometer. In addition, magnetic switches (not shown) in the lower body of the spectrophotometer 10 are monitored by the computer 74 to determine the type of sample interface device installed at the lower end 14. Magnets on the interface devices activate one or more of the magnetic switches at the lower end 14 of the spectrophotometer 10 in order to indicate to the computer 74 the type of interface device installed. Since each type of sample interface device has a different arrangement of magnets, the type of interface device installed can be automatically determined by the computer 74 of the spectrophotometer 10.

A further feature of the preferred embodiment is the capability of electronically communicating with the computer 74 using an external device 75, such a personal computer, as shown in Fig. 6. Such communication can be accomplished by connecting a communication port 99 (shown in Fig. 1) of the spectrophotometer 10 to a communication port of the external device 75, such as an RS-232 serial port. Using software control signals, a user may communicate between the computer 74 of the spectrophotometer 10

and the external device 75. Also, the internal programming of the computer 74 may be altered due to control signals communicated. For this situation, the internal programming of the computer 74 would be stored in non-volatile programmable memory, such as FLASH ram.

The present invention having been thus described with particular reference to the preferred forms thereof, it will be obvious that various changes and modifications may be made therein without departing from the spirit and scope of the invention as defined in the appended claims. For example, the present invention as described above may be utilized for a wide variety of signal measuring devices, such as a radiometer. Although a radiometer is not necessarily used to illuminate a sample with a light source, it may utilize the reference dual beam system and spectral separator of the present invention by using its own light source as a reference. Thus, the present invention is not restricted to spectrophotometers and is applicable to a wide-variety of signal measuring device that desire portability, immunity to instrument orientation, regulation of signal level, and other benefits described above.

Wherefore we claim:

1. A portable device for measuring color of a sample. comprising:

means for illuminating the sample;

means for transmitting a reference light from said illuminating means;

means for transmitting a sample light reflected from the sample;

means for receiving said reference light and said sample light, and for separating said reference light and said sample light into spectral components, said separating means producing reference signals and sample signals corresponding to the levels of spectral components of said reference light and said sample light, respectively; and

means, responsive to said separating means, for analyzing said sample signals relative to said reference signals to provide colorimetric data, and means for outputting said colorimetric data.

2. The portable device of claim 1, wherein said separating means comprises a plurality of reference detectors and a plurality of sample detectors.

3. The portable device of claim 2, wherein each detector of said plurality of reference detectors and said plurality of sample detectors is comprised of silicon.

4. The portable device of claim 3, wherein said plurality of reference detectors and said plurality of sample detectors each includes a single row of sixteen individual detectors.

5. The portable device of claim 2, wherein said separating means further comprises:

a plurality of reference interference filters located directly adjacent to said plurality of reference detectors; and

a plurality of sample interference filters located directly adjacent to said plurality of sample detectors.

6. The portable device of claim 3, wherein each detector of said plurality of reference detectors and said plurality of sample detectors is directly connected to an amplifier.

7. The portable device of claim 6, wherein each amplifier of each detector is connected to said analyzing means.

8. The portable device of claim 1, further comprising means for conveying light from said illuminating means to the sample.

9. The portable device of claim 8, wherein said conveying means and said means for transmitting said reference light each further comprises a filter that absorbs infrared light waves.

10. The portable device of claim 9, wherein said conveying means comprises a plurality of optic fibers arranged about the sample at 45° angles from a receiving axis of said sample light.

11. The portable signal measuring device of claim 1, further comprising performing means that comprises:

a pair of programmable gain amplifiers for associating a particular predetermines electrical gain to each of said reference signals and said sample signals and for producing a pair of analog outputs;

a pair of multiplexers for serially addressing each of said reference signals and said sample signals to said pair of programmable gain amplifiers;

a pair of analog-to-digital converters for receiving said analog outputs and for producing a pair of corresponding digital outputs; and

means for computing a variety of different color scales and functions based on said pair of digital outputs.

12. A portable device for measuring color of a sample, comprising:

means for illuminating the sample;

means for transmitting light from said illuminating means to the sample and for receiving a sample light from the sample;

an integration chamber interposed between said illuminating means and said transmitting means, for homogenizing said light from said illuminating means and for negating bias;

means for receiving said sample light and for separating said sample light into spectral components, said separating means producing sample signals corresponding to levels of spectral components of said sample light; and

means, responsive to said separating means, for analyzing said sample signals to provide colorimetric data, and for outputting said colorimetric data.

13. The portable device of claim 12, wherein said integrating chamber collects and reflects said light from said illuminating means over a plurality of angles.

14. A portable device for measuring color of a sample, comprising:

means for illuminating the sample;

means for transmitting a sample light reflected from the sample;

means for receiving said sample light and for separating said sample light into spectral components, said separating means producing sample signals corresponding to levels of spectral components of said sample light; and

means, responsive to said separating means, for analyzing said sample signals, said analyzing means including at least one programmable gain amplifier for associating a particular predetermines electrical gain level to each of said sample signals.

15. The portable device of claim 14, wherein said programmable gain amplifier dynamically optimizes said gain level for each of said sample signals, responsive to a configuration change of said illuminating means.

16. The portable device of claim 14, wherein said analyzing means further comprises:

a multiplexer for serially addressing each of said sample signals to said programmable gain amplifiers;

an analog-to-digital converter for receiving each of said gain levels and for producing corresponding digital outputs; and

means for computing a variety of different color scales and functions based on said digital outputs.

17. A portable device for measuring color of a sample, comprising:

means for illuminating the sample;

means for transmitting a reference light from said illuminating means;

means for transmitting a sample light reflected from the sample;

means for receiving said reference light and said sample light, and for separating said reference light and said sample light into spectral components, said separating means being effective to produce reference signals and sample signals corresponding to the levels of spectral components of said reference light and said sample light, respectively;

means, responsive to said separating means, for measuring and calibrating said sample signals and said reference signals and for comparing said sample signals relative to said reference signals to provide colorimetric data; and

means, responsive to said measuring and comparing means, for outputting said colorimetric data.

18. The portable device of claim 17, wherein said analyzing means includes a programmable gain amplifier for associating a particular predetermines electrical gain level to each of said sample signals.

19. The portable device of claim 18, wherein said programmable gain amplifier optimizes said gain level for each of said sample signals, responsive to a configuration change of said illuminating means.

20. The portable device of claim 17, wherein said analyzing means further comprises:

a multiplexer for serially addressing each of said sample signals to said programmable gain amplifiers;

an analog-to-digital converter for receiving each of said gain levels and for producing corresponding digital outputs; and

means for computing a variety of different color scales and functions based on said digital outputs.

AMENDED CLAIMS

[received by the International Bureau on 05 April 1996 (05.04.96) ; original claims 11,14,16-18 and 20 amended; new claims 21-56 added; remaining claims unchanged (14 pages)]

1. A portable device for measuring color of a sample, comprising:

means for illuminating the sample;

means for transmitting a reference light from said illuminating means;

means for transmitting a sample light reflected from the sample;

means for receiving said reference light and said sample light, and for separating said reference light and said sample light into spectral components, said separating means producing reference signals and sample signals corresponding to the levels of spectral components of said reference light and said sample light, respectively; and

means, responsive to said separating means, for analyzing said sample signals relative to said reference signals to provide colorimetric data, and means for outputting said colorimetric data.

2. The portable device of claim 1, wherein said separating means comprises a plurality of reference detectors and a plurality of sample detectors.

3. The portable device of claim 2, wherein each detector of said plurality of reference detectors and said plurality of sample detectors is comprised of silicon.

4. The portable device of claim 3, wherein said plurality of reference detectors and said plurality of sample detectors each includes a single row of sixteen individual detectors.

5. The portable device of claim 2, wherein said separating means further comprises

a plurality of reference interference filters located directly adjacent to said plurality of reference detectors; and

a plurality of sample interference filters located directly adjacent to said plurality of sample detectors.

6. The portable device of claim 3, wherein each detector of said plurality of reference detectors and said plurality of sample detectors is directly connected to an amplifier.

7. The portable device of claim 6, wherein each amplifier of each detector is connected to said analyzing means.

8. The portable device of claim 1, further comprising means for conveying light from said illuminating means to the sample.

9. The portable device of claim 8, wherein said conveying means and said means for transmitting said reference light each further comprises a filter that absorbs infrared light waves.

10. The portable device of claim 9, wherein said conveying means comprises a plurality of optic fibers arranged about the sample at 45° angles from a receiving axis of said sample light.

11. The portable device of claim 1, further comprising performing means that includes:

a pair of programmable gain amplifiers for associating a particular electrical gain to each of said reference signals and said sample signals and for producing a pair of analog outputs within a particular reference range and a particular sample range, respectively.

12 A portable device for measuring color of a sample, comprising:

means for illuminating the sample;

means for transmitting light from said illuminating means to the sample and for receiving a sample light from the sample;

an integration chamber interposed between said illuminating means and said transmitting means, for homogenizing said light from said illuminating means and for negating bias;

means for receiving said sample light and for separating said sample light into spectral components, said separating means producing sample signals corresponding to levels of spectral components of said sample light; and

means, responsive to said separating means, for analyzing said sample signals to provide colorimetric data, and for outputting said colorimetric data.

13. The portable device of claim 12, wherein said integrating chamber collects and reflects said light from said illuminating means over a plurality of angles.

14 A portable device for measuring color of a sample, comprising:

means for illuminating the sample;

means for transmitting a sample light reflected from the sample;

means for receiving said sample light and for separating said sample light into spectral components, said separating means producing sample signals corresponding to levels of spectral components of said sample light; and

means, responsive to said separating means, for analyzing said sample signals, said analyzing means including at least one programmable gain amplifier for associating a particular predetermines electrical gain level to each of said sample signals and for producing an analog output within a particular sample range.

15. The portable device of claim 14, wherein said programmable gain amplifier dynamically optimizes said gain level for each of said sample signals, responsive to a configuration change of said illuminating means.

16. The portable device of claim 14, wherein said analyzing means further comprises:

a multiplexer for serially addressing each of said sample signals to said programmable gain amplifier;

an analog-to-digital converter for receiving each of said gain levels and for producing corresponding digital outputs; and

means for computing a variety of different color scales and functions based on said digital outputs.

17 A portable device for measuring color of a sample, comprising:

AMENDED SHEET (ARTICLE 19)

means for illuminating the sample;

means for transmitting a reference light from said illuminating means;

means for transmitting a sample light reflected from the sample;

means for receiving said reference light and said sample light, and for separating said reference light and said sample light into spectral components, said separating means being effective to produce reference signals and sample signals corresponding to the levels of spectra components of said reference light and said sample light, respectively;

analyzing means, responsive to said separating means, for measuring and calibrating said sample signals and said reference signals and for comparing said sample signals relative to said reference signals to provide colorimetric data; and

means, responsive to said measuring and comparing means, for outputting said colorimetric data.

18. The portable device of claim 17, wherein said analyzing means includes a programmable gain amplifier for associating a particular electrical gain level to each of said sample signals and f r producing an analog utput within a particular sampl range.

19. The portable device of claim 18, wherein said programmable gain amplifier optimizes said gain level for each of said sample signals, responsive to a configuration change of said illuminating means.

20. The portable device of claim 17, wherein said analyzing means further comprises:

a multiplexer for serially addressing each of said sample signals to said programmable gain amplifier;

an analog-to-digital converter for receiving each of said gain levels and for producing corresponding digital outputs; and

means for computing a variety of different color scales and functions based on said digital outputs.

21. The portable device of claim 1, wherein said means for transmitting a reference light and said means for transmitting a sample light are fiber optic bundles.

22. The portable device of claim 1, wherein said illuminating means has a filament in order to generate a spectral energy distribution that is a direct function of a temperature of the filament.

23. The portable device f claim 1, wherein said analyzing means, based on said sample signals and said reference signals, compensates data spectrally and photometrically for any variations produced by said illuminating means.

24. The portable device of claim 1, wherein said illuminating means is a gas-filled tungsten lamp operated in a constant current mode.

25. The portable device of claim 11, wherein said particular reference range is a portion of the full dynamic range of said reference signals, and said particular sample range is a portion of the full dynamic range of said sample signals.

26. The portable device of claim 11, wherein each of said pair of analog outputs has a substantially uniform signal level.

27 The portable device of claim 11, wherein said performing means comprises:

a pair of multiplexers for serially addressing each of said reference signals and said sample signals to said pair of programmable gain amplifiers;

a pair of analog-to-digital converters for receiving said analog outputs and for producing a pair of corresponding digital outputs; and

means for computing a variety of different color scales and functions based on said pair f digital outputs.

28. The portable device of claim 1, wherein said analyzing means includes correction means for obtaining raw data from a series of known color tiles at individual wavelengths and determining a set of correction coefficients.

29. The portable device of claim 28, further comprising a computer means and a memory portion wherein said correction coefficients of said correction means are stored in said memory portion and used by said computer means to determine said colorimetric data.

30. The portable device of claim 1, wherein said analyzing means includes means for processing said sample signals and said reference signals so that said illuminating means, said receiving means and said analyzing means may be used at any orientation without affecting the integrity of their measurements.

31. The portable device of claim 1, wherein said analyzing means includes means for processing said sample signals and said reference signals so that said illuminating means, said receiving means and said analyzing means compensate for temperature variations and are relatively temperature independent.

32. The portable device of claim 1, wherein said receiving and separating means include interference filters that are not characteristically affected by environmental temperature variations.

33. The portable device of claim 14, wherein said means for transmitting a reference light and said means for transmitting a sample light are fiber optic bundles.

34. The portable device of claim 14, wherein said illuminating means has a filament in order to generate a spectral energy distribution that is a direct function of a temperature of the filament.

35. The portable device of claim 14, wherein said analyzing means, based on said sample signals and said reference signals, compensates data spectrally and photometrically for any variations produced by said illuminating means.

36. The portable device of claim 14, wherein said illuminating means is a gas-filled tungsten lamp operated in a constant current mode.

37. The portable device of claim 14, further comprising performing means that includes a pair of programmable gain amplifiers for associating a particular electrical gain to each of said reference signals and said sample signals, and for producing a pair of analog outputs within a particular reference range and a particular sample range, respectively.

38. The portable device of claim 37, wherein said particular reference range is a portion of the full dynamic range of said reference signals, and said particular sample range is a portion of the full dynamic range of said sample signals.

39. The portable device of claim 37, wherein each of said pair of analog outputs has a substantially uniform signal level.

40. The portable device of claim 14, wherein said analyzing means includes correction means for obtaining raw data from a series of known color tiles at individual wavelengths and determining a set of correction coefficients.

41. The portable device of claim 40, further comprising a computer means and a memory portion wherein said correction coefficients of said correction means are stored in said memory portion and used by said computer means to determine said colorimetric data.

42. The portable device of claim 14, wherein said analyzing means includes means for processing said sample signals and said reference signals so that said illuminating means, said receiving means and said analyzing means may be used at any orientation without affecting the integrity of their measurements.

43 The portable device of claim 14, wherein said analyzing means includes means for processing said sample signals and said reference signals so that said illuminating

means, said receiving means and said analyzing means compensate for temperature variations and are relatively temperature independent.

44. The portable device of claim 14, wherein said receiving and separating means include interference filters that are not characteristically affected by environmental temperature variations.

45. The portable device of claim 17, wherein said means for transmitting a reference light and said means for transmitting a sample light are fiber optic bundles.

46. The portable device of claim 17, wherein said illuminating means has a filament in order to generate a spectral energy distribution that is a direct function of a temperature of the filament.

47 The portable device of claim 17, wherein said analyzing means, based on said sample signals and said reference signals, compensates data spectrally and photometrically for any variations produced by said illuminating means.

48 The portable device of claim 17, wherein said illuminating means is a gas-filled tungsten lamp operated in a constant current mode.

49. The portabl device of claim 17, further comprising performing means that includes a pair of programmable gain amplifiers for associating a particular electrical gain

to each of said reference signals and said sample signals, and for producing a pair of analog outputs within a particular reference range and a particular sample range, respectively.

50. The portable device of claim 49, wherein said particular reference range is a portion of the full dynamic range of said reference signals, and said particular sample range is a portion of the full dynamic range of said sample signals.

51. The portable device of claim 49, wherein each of said pair of analog outputs has a substantially uniform signal level.

52. The portable device of claim 17, wherein said analyzing means includes correction means for obtaining raw data from a series of known color tiles at individual wavelengths and determining a set of correction coefficients.

53 The portable device of claim 52, further comprising a computer means and a memory portion wherein said correction coefficients of said correction means are stored in said memory portion and used by said computer means to determine said colorimetric data.

54. The portable device of claim 17, wherein said analyzing means includes means for processing said sample signals and said reference signals so that said illuminating means, said receiving means and said analyzing means may be used at any orientation without affecting the integrity of their measurements.

5:. The portable device of claim 17, wherein said analyzing means includes means for processing said sample signals and said reference signals so that said illuminating means, said receiving means and said analyzing means compensate for temperature variations and are relatively temperature independent.

5€. The portable device of claim 17, wherein said receiving and separating means include interference filters that are not characteristically affected by environmental temperature variations.

STATEMENT UNDER ARTICLE 19

This application now contains claims 1 through 56. Claims 11, 14, 16, 17, 18 and 20 have been amended, and claims 21 through 56 have been added.

Claim 16, 18 and 20 have been amended to correct innocucus typographical errors. Also, claims 20 has been amended to depend from claim 18 instead of claims 17. In additicn, claim 17 has been amended so that certain claims that depend from independent claim 17, namely claims 18, 20 and new claims 47, 52, 54 and 55, may more easily reference same.

The Search R port cites as particularly relevant the following United States patents:

U.S. Patent No. 4,968,148 to Chow, et al. ("Chow, et al. patent"), which issued on November 6, 1990, titled SINGLE SOURCE MULTI-SITE PHOTOMETRIC MEASUREMENT SYSTEM.

U.S. Patent No. 4,995,727 to Kawagoe, et al. ("Kawagoe '727 patent"), which issued on February 26, 1991, titled COMPACT DIFFUSION LIGHT MIXING BOX AND COLORIMETER.

U.S. Patent No. 5,175,697 to Kawagoe, et al. ("Kawagoe '697 patent"), which issued on December 29, 1992, titled SPECTROPHOTOMETER FOR ACCURATELY MEASURING LIGHT INTENSITY IN A SPECIFIC WAVELENGTH REGION.

Independent claim 1 provides a portable device for measuring color of a sample having "means for transmitting a reference light from said illuminating means", namely a fiber optic bundle. By using this fiber optic bundle, the present invention has great flexibility in arranging its inner components without sacrificing features or performance quality. The Chow, et al. patent states that light emitted by a tungsten-quartz bulb is directed to a chopper. The Kawagoe '727 states that a light source directs light into an integrating sphere wh re it illuminates a sampl . The Kawagoe '697 patent states that part f the light emitted from a pulse xen n lamp is incited into one spectral sensor,

and another part f th light illuminat s a sample so that the light reflected falls onto another spectral sensor. Accordingly, the Chow, et al. patent, Kawagoe '727 patent and Kawagoe '697 patent do not describe any means for transmitting reference light from the light source.

In addition, there is no suggestion in the cited patents that any means is necessary for transmitting reference light. Absent such suggestion, a person skilled in the art who was looking for a portable design for a color measuring device would hardly be disposed to consider a patent like the Chow, et al. patent, Kawagoe '727 patent or Kawagoe '697 patent, since these patents do not address issues concerning portability of color measuring devices, let alone any structure that would resolve such issues. Therefore, claim 1 patentably distinguish over the cited patents and the combination of same.

Claims 2 through 10 depend from independent claim 1 and, thus, they are patentable over the cited patents and the combination of same for the reasons stated above for claim 1. In addition, claims 8 through 10 recite "means for conveying light from said illuminating means to the sample". The Chow, et al. patent, Kawagoe '727 patent and Kawagoe '697 patent do not describe or suggest such means for conveying light from the light source to the sample. Al o, the Kawagoe '697 patent does not describe a filter that absorbs infrared light waves provided in claim 9 or optic

fibers arranged about the sample at 45° angles provided in claim 10. In addition, claim 11 has means "for producing a pair of analog outputs within a particular reference range and a particular sample range, respectively" which is not provided in the above cited patents. Therefore, claims 8 through 11 further distinguish patentably over the cited patents and the combination of same.

Claim 12 includes means for transmitting light from the light source to the sample. Claim 13 depends from and includes the limitations of claim 12. In addition, claim 13 provides an integrating chamber that "collects and reflects said light from said illuminating means over a plurality of angles". In contrast, the Chow, et al. patent, Kawagoe, '727 patent and Kawagoe '697 patent do not describe or suggest any means for transmitting light from the light source to the sample nor the claimed integrating chamber. Thus, claims 12 and 13 patentably distinguishes over the cited patents and the combination of same.

Independent claim 14 includes means "for producing an analog output within a particular sample range". The Chow, et al. patent, Kawagoe '727 patent and Kawagoe '697 patent do not describe such means and, therefore, claim 14 patentably distinguishes over the above cited patents and th combination of same.

Claims 15 and 16 d pend from independent claim 14 and, thus, are patentable over the Chow, et al. patent, Kawagoe '727 patent and Kawagoe '697 patent for the reasons stated above with respect to independent claim 14. Therefore, claims 15 and 16 patentably distinguish over the cited patents and the combination of same.

Similar to claim 1, independent claim 17 provides a portable device for measuring color of a sample having "means for transmitting a reference light from said illuminating means". The Chow, et al. patent, Kawagoe '727 patent and Kawagoe '697 patent do not describe any means for transmitting a reference light from a light source. Therefore, claim 17 patentably distinguishes over the cited patents and the combination of same.

Claims 18 through 20 depend from independent claim 17 and, thus, are patentable over the above cited patent for the reasons stated above with respect to independent 17. In addition, claim 18 includes means "for producing an analog output within a particular sample range". The above cited patents do not describe or suggest the PGA provided in claim 18. Therefore, claims 18 through 20 patentably distinguish over the cited patents and combination of same.

New claims 21 through 56 are pres nted to mor clearly cover certain asp cts of applicant's portabl color measuring d vice that have already been d scribed above.

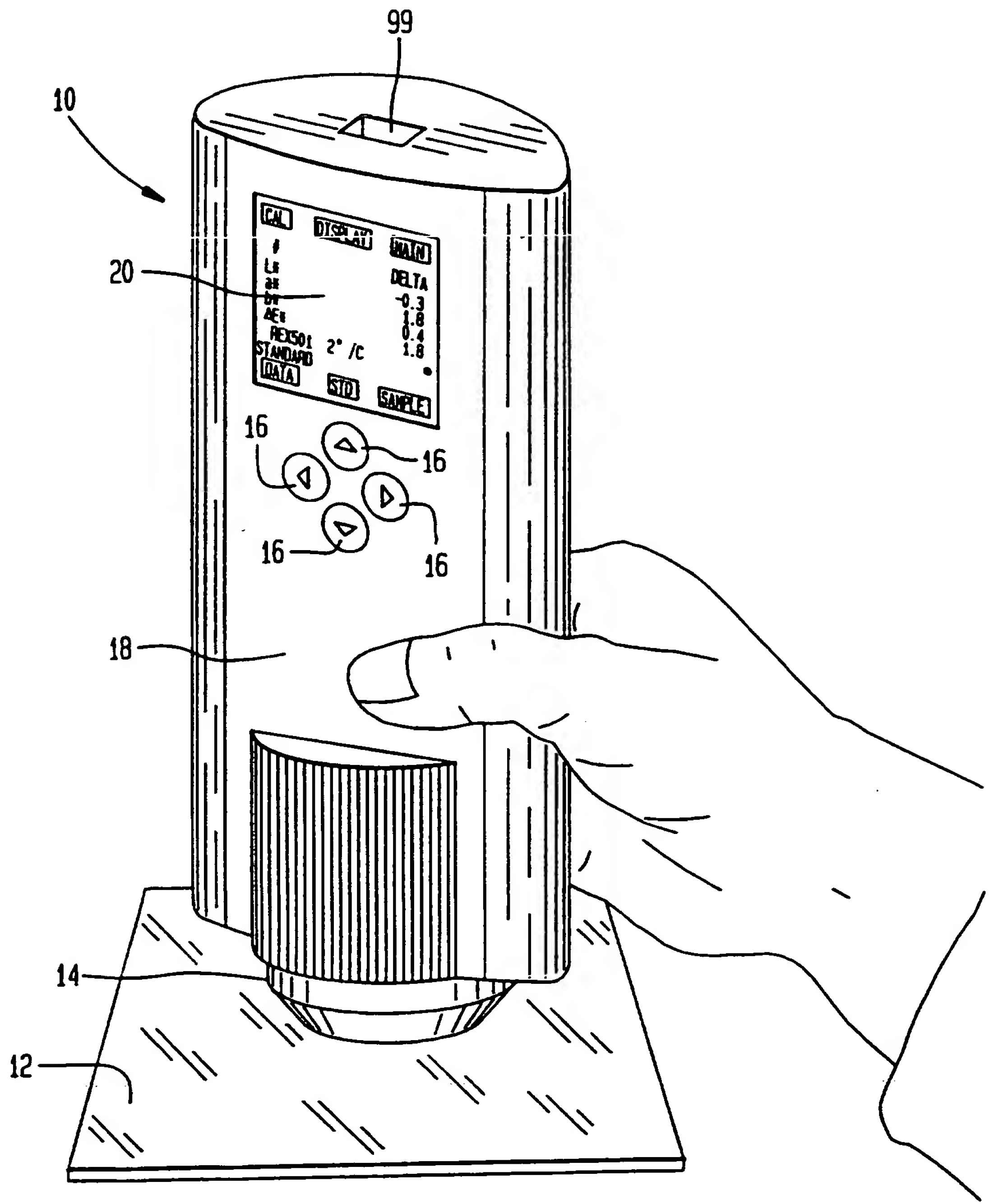
New claims 21, 33 and 45 state that the transmitting means of independent claims 1, 14 and 17, respectively, are fiber optic bundles. Also, new claims 22 through 24, 34 through 36 and 46 through 48 provide that the light source, such as a tungsten lamp, generates a spectral energy distribution ("SED") that is a direct function of a temperature of the light source's filament. In addition, new claims 25, 26, 37, 38, 39, 49, 50 and 51 provide that each analog output range of the PGA's is a portion of a full dynamic range of the original signals and has a substantially uniform signal level. Further, new claim 27 depends from claim 11 and merely includes the elements that have been deleted from claim 11. The Chow, et al. patent, Kawagoe '727 patent and Kawagoe '697 patent do not describe or suggest that which is claimed in new claims 21 through 27, 33 through 39 and 45 through 51. Therefore, for the above reasons, allowance of claims 21 through 27, 33 through 39 and 45 through 51 is warranted.

New claims 28, 29, 40, 41, 52 and 53 provide the correction means described in the present application. In addition, claims 30, 42 and 54 provide processing means that compensates for orientation changes, and claims 31, 32, 43, 44, 55 and 56 provide proc ssing means and interference filters that compensate for temperature variations. Th Chow, t al. patent, Kawagoe '727 patent and Kawagoe '697 patent do not describe or suggest that which is claimed in

new claims 28 through 30, 40 through 44 and 52 through 56. Therefore, allowance of claims 28 through 30, 40 through 44 and 52 through 56 is respectfully requested.

In view of the foregoing, applicant respectfully submits that all claims presented herein, namely claims 1 through 56, patentably distinguish over each cited reference and the cited combination of same. Thus, applicant respectfully requests favorable consideration of the claims of the present application.

Due to the amendments to claims 11, 14, 16, 17, 18 and 20 and the addition of new claims 21 through 56 set forth above, applicant is submitting herewith replacement pages 39 through 47 and new pages 48 through 53 to the above application.


99
10
CAL
DISPLAY
MAIN
DELTA
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1.8
0.4
1.8
2° /C
STANDARD
DATA
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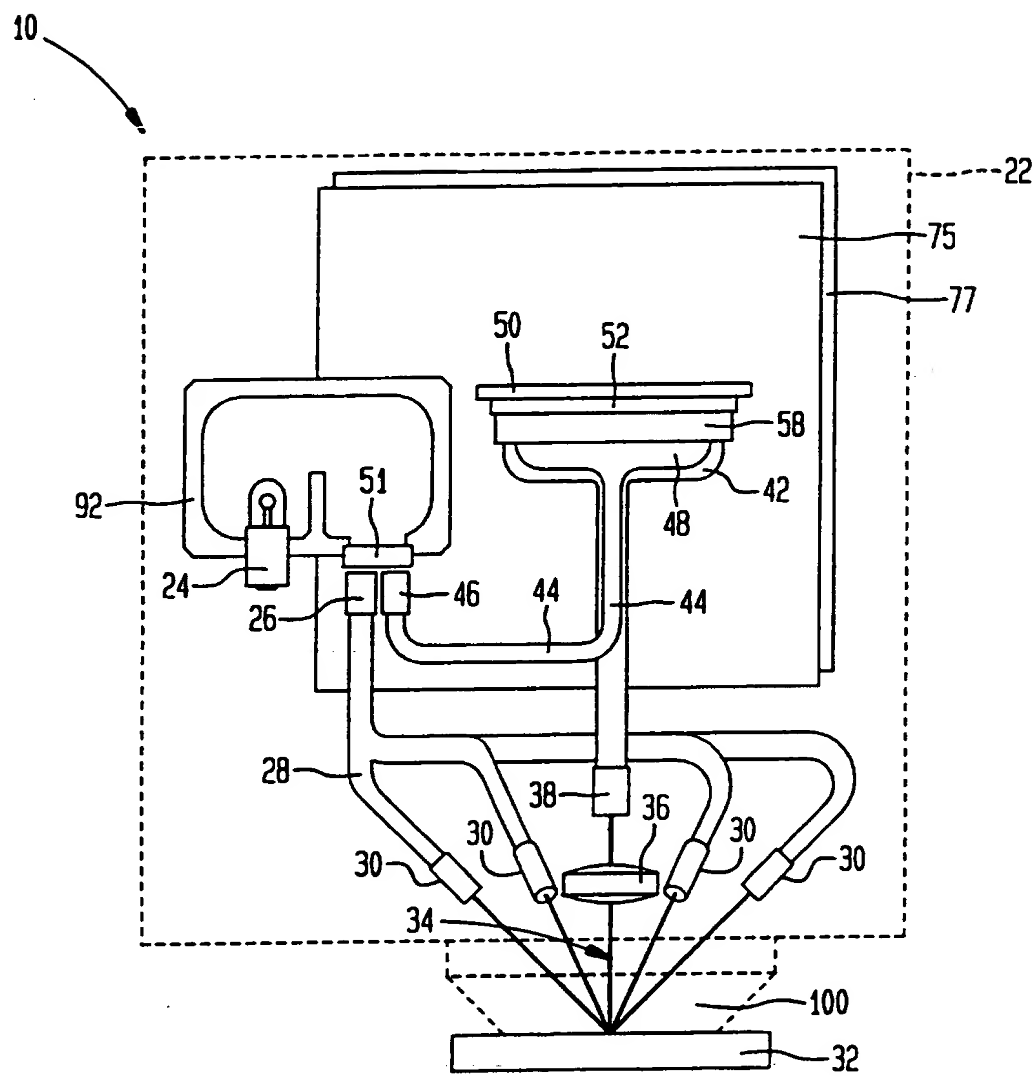
SAMPLE
20
16
16
16
16
18
14
12

FIG. 1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22
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52
58
42
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92
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30
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100
32

FIG. 2

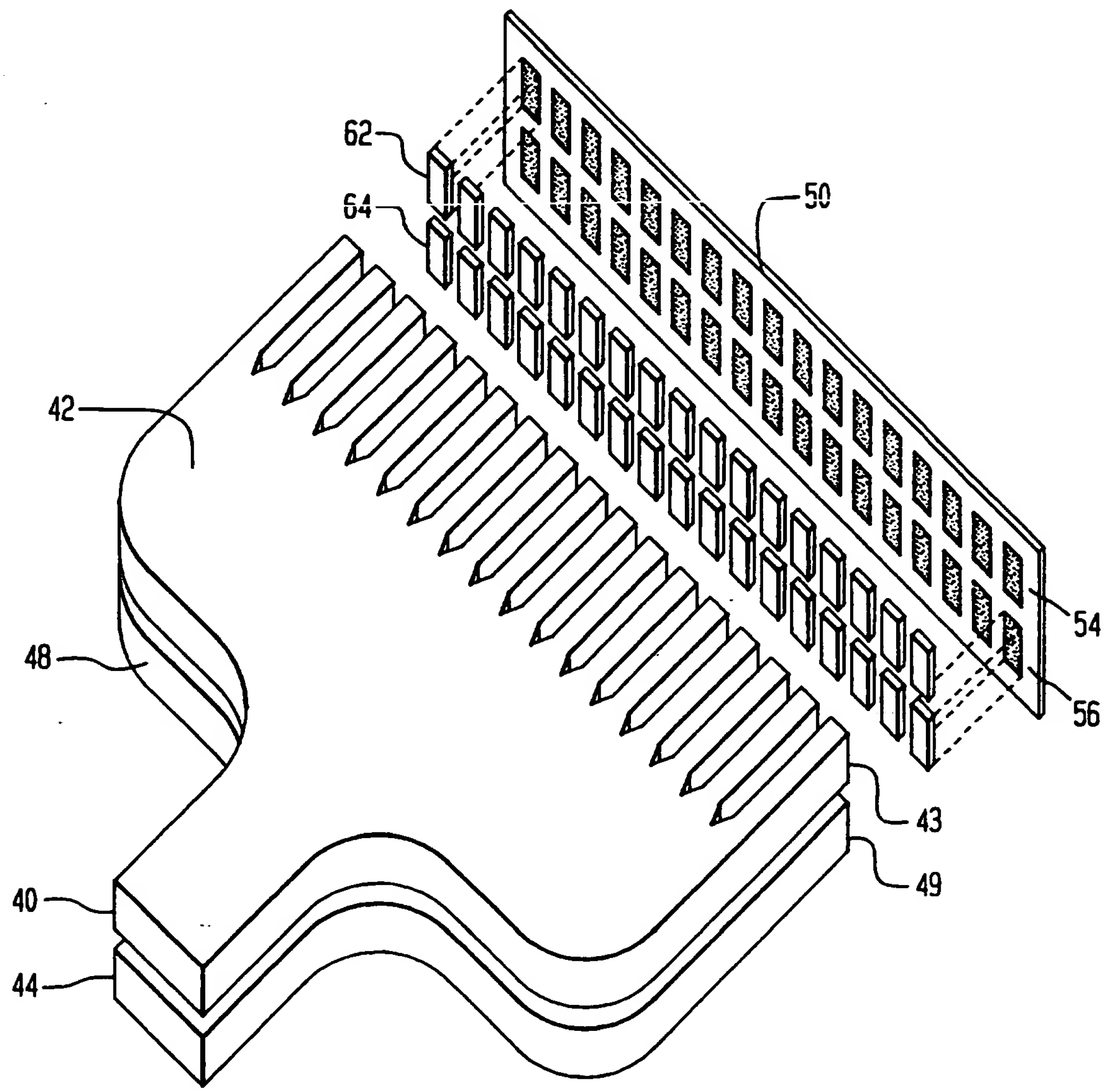


FIG. 2A

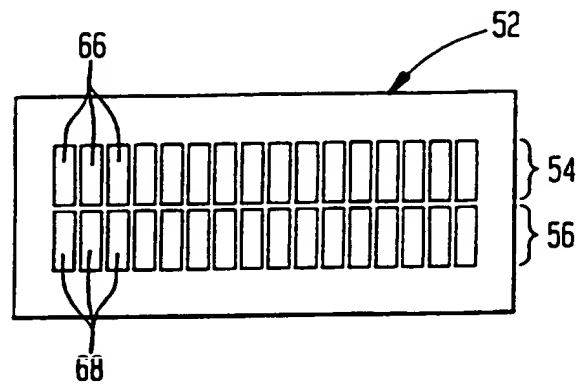


FIG. 3

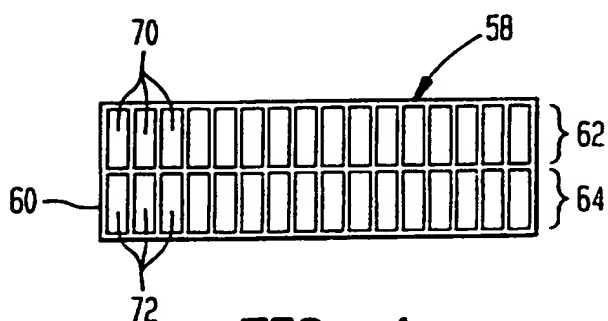


FIG. 4

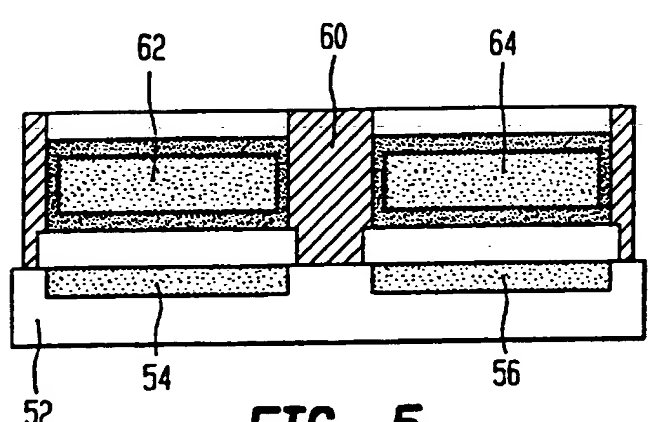
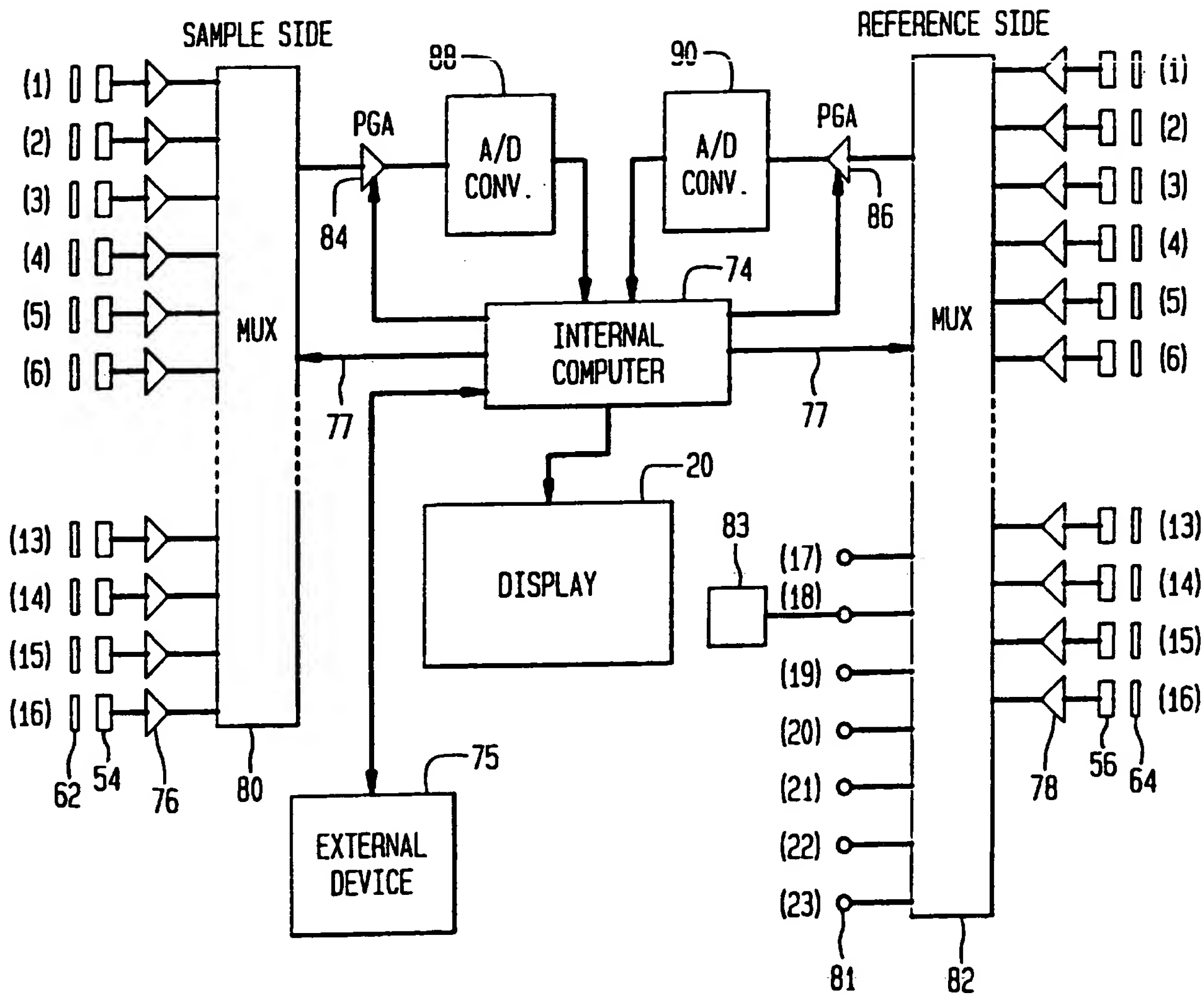


FIG. 5


SAMPLE SIDE
REFERENCE SIDE
(1)
(2)
(3)
(4)
(5)
(6)
(13)
(14)
(15)
(16)
62
54
76
80
MUX
PGA
84
88
A/D CONV.
90
A/D CONV.
PGA
86
74
INTERNAL COMPUTER
77
77
20
DISPLAY
75
EXTERNAL DEVICE
83
(17)
(18)
(19)
(20)
(21)
(22)
(23)
81
82
MUX
(1)
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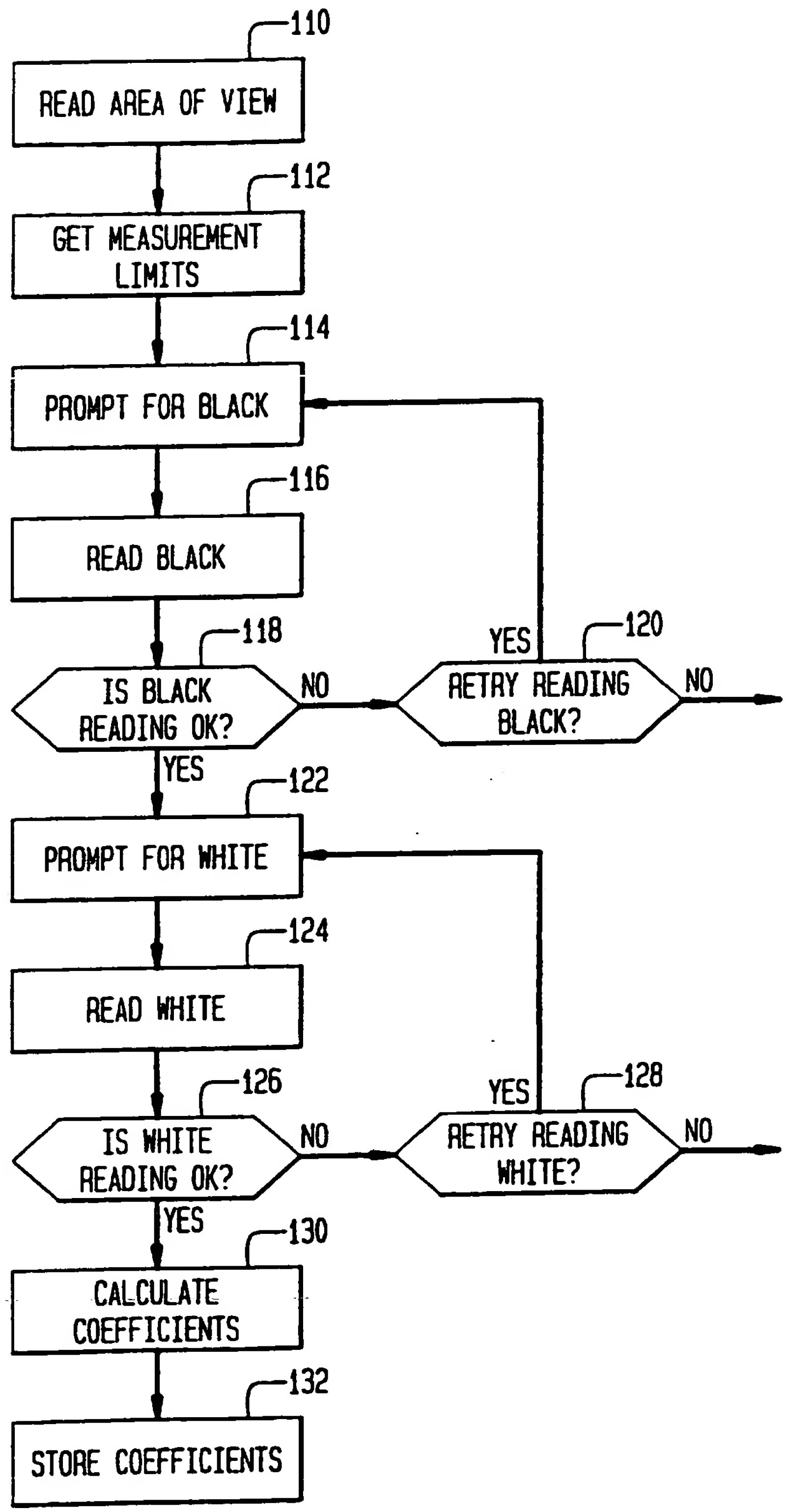
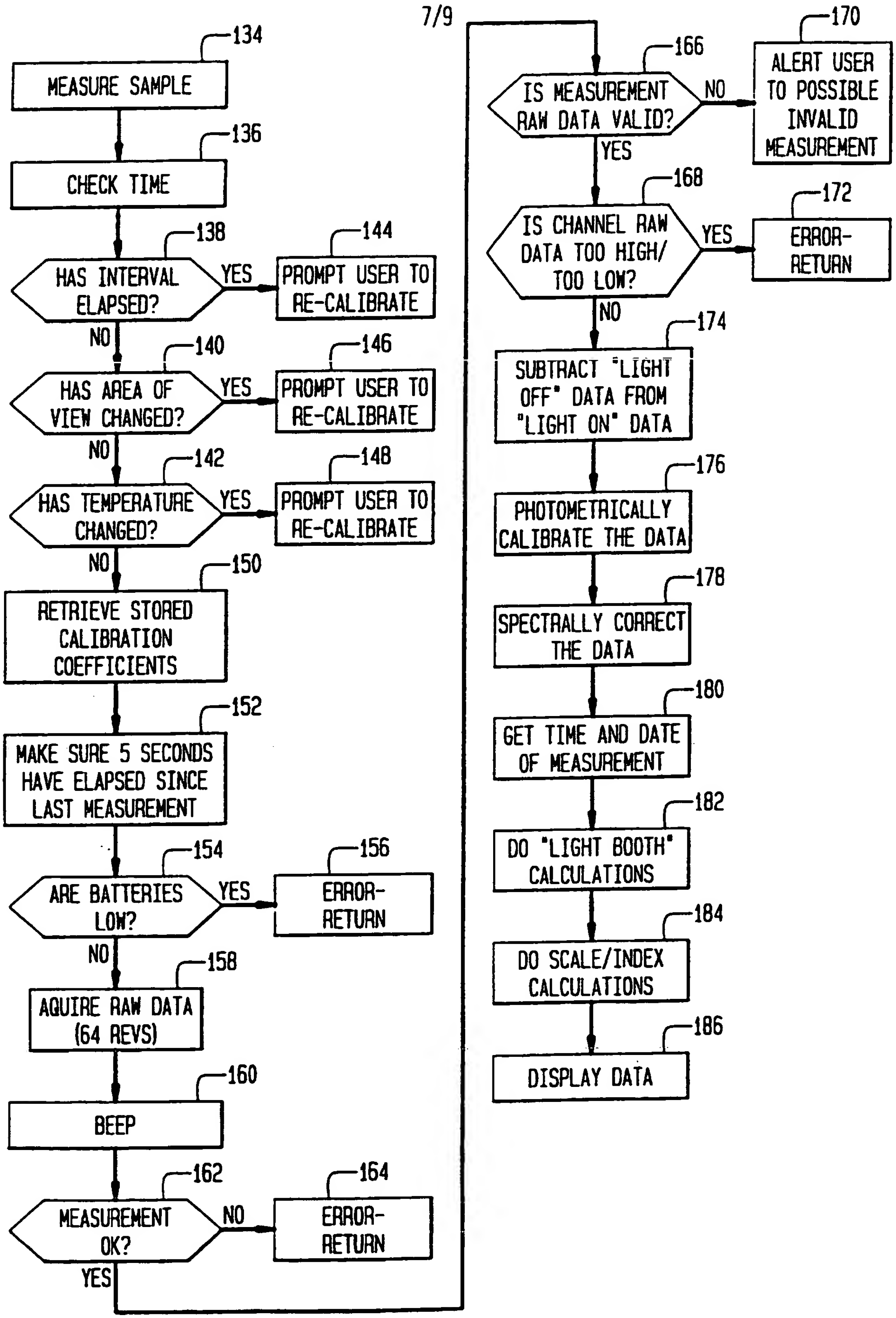
(13)
(14)
(15)
(16)
78
56
64

FIG. 6

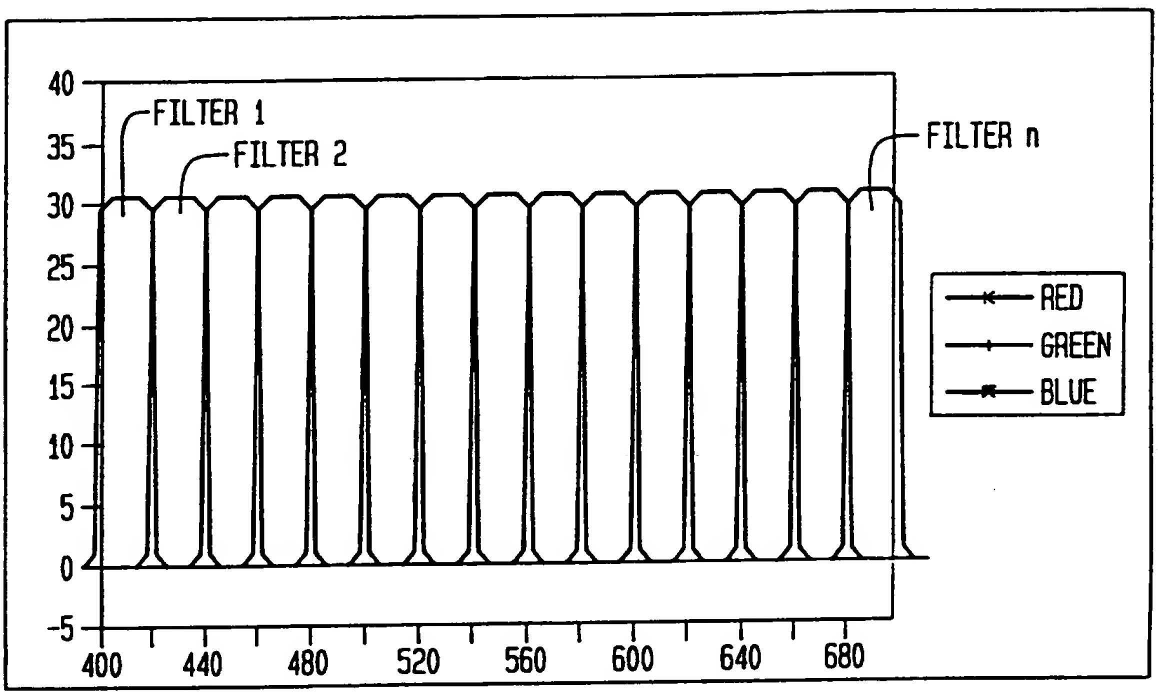


110
READ AREA OF VIEW
112
GET MEASUREMENT LIMITS
114
PROMPT FOR BLACK
116
READ BLACK
118
IS BLACK READING OK?
NO
YES
120
RETRY READING BLACK?
YES
NO
122
PROMPT FOR WHITE
124
READ WHITE
126
IS WHITE READING OK?
NO
YES
128
RETRY READING WHITE?
YES
NO
130
CALCULATE COEFFICIENTS
132
STORE COEFFICIENTS

FIG. 7



134
MEASURE SAMPLE
136
CHECK TIME
138
HAS INTERVAL ELAPSED?
YES
144
PROMPT USER TO RE-CALIBRATE
NO
140
HAS AREA OF VIEW CHANGED?
YES
146
PROMPT USER TO RE-CALIBRATE
NO
142
HAS TEMPERATURE CHANGED?
YES
148
PROMPT USER TO RE-CALIBRATE
NO
150
RETRIEVE STORED CALIBRATION COEFFICIENTS
152
MAKE SURE 5 SECONDS HAVE ELAPSED SINCE LAST MEASUREMENT
154
ARE BATTERIES LOW?
YES
156
ERROR-RETURN
NO
158
AQUIRE RAW DATA (64 REVS)
160
BEEP
162
MEASUREMENT OK?
NO
164
ERROR-RETURN
YES
166
IS MEASUREMENT RAW DATA VALID?
NO
170
ALERT USER TO POSSIBLE INVALID MEASUREMENT
YES
168
IS CHANNEL RAW DATA TOO HIGH/ TOO LOW?
YES
172
ERROR-RETURN
NO
174
SUBTRACT "LIGHT OFF" DATA FROM "LIGHT ON" DATA
176
PHOTOMETRICALLY CALIBRATE THE DATA
178
SPECTRALLY CORRECT THE DATA
180
GET TIME AND DATE OF MEASUREMENT
182
DO "LIGHT BOOTH" CALCULATIONS
184
DO SCALE/INDEX CALCULATIONS
186
DISPLAY DATA


FILTER 1
FILTER 2
FILTER n
RED
GREEN
BLUE
40
35
30
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20
15
10
5
0
-5
400
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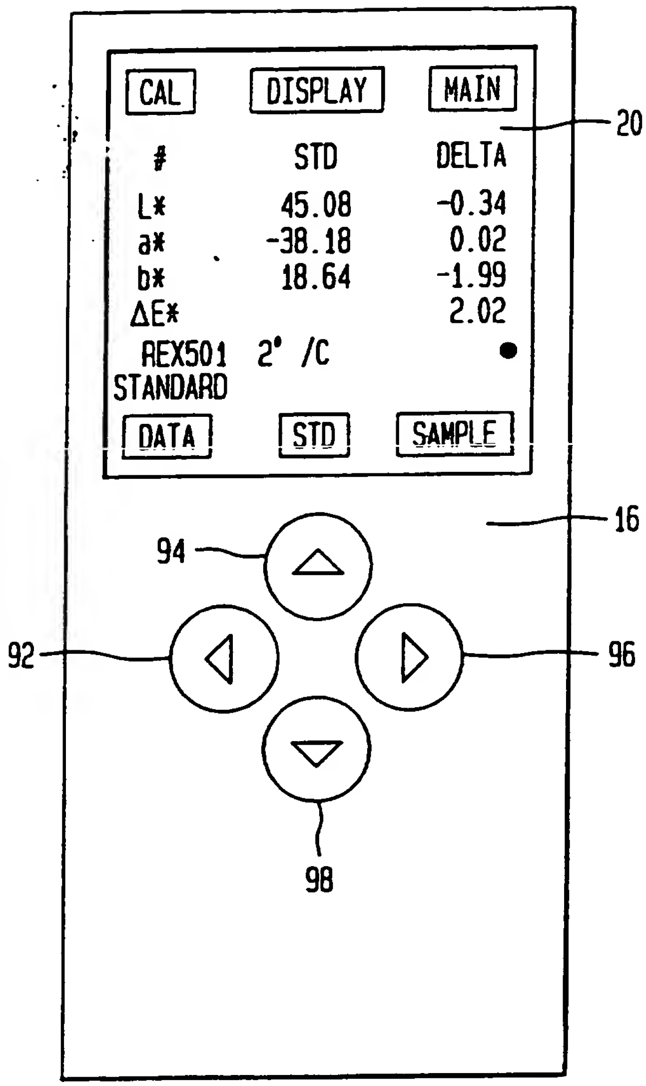
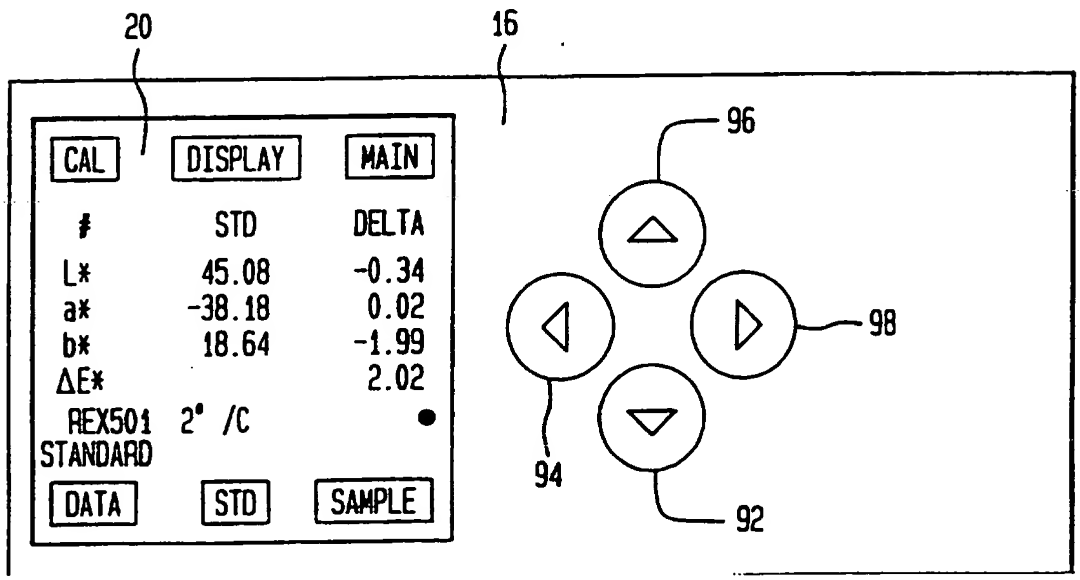
560
600
640
680

FIG. 9



CAL
DISPLAY
MAIN
20
#
STD
DELTA
L* 45.08 -0.34
a* -38.18 0.02
b* 18.64 -1.99
ΔE* 2.02
REX501 2° /C
STANDARD
DATA
STD
SAMPLE
16
94
92
96
98

FIG. 10



20
16
CAL
DISPLAY
MAIN
#
STD
DELTA
L* 45.08 -0.34
a* -38.18 0.02
b* 18.64 -1.99
ΔE* 2.02
REX501 2° /C
STANDARD
DATA
STD
SAMPLE
96
98
94
92

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/13755

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :GOIN 21/27
US CL :356/419, 425
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 356/402, 419, 425

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X/Y	US,A, 5,175,697 (KAWAGOE et al.) 29 December 1992. See fig. 1	1-10, 17/ 11, 14-16, 18-20
Y	US,A, 4,968,148 (CHOW et al.) 06 November 1990. See column 12, lines 40-55	11, 14-16, 18-20
X	US,A, 4,995,727 (KAWAGOE et al) 26 February 1991. See fig. 14	12, 13

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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Date of the actual completion of the international search	Date of mailing of the international search report
30 JANUARY 1996	06 FEB 1996
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks	Authorized officer